PN00403

PHYSICAL SCIENCE LABORATORY

NEW MEXICO STATE UNIVERSITY

University Park, New Mexico

NASA RADINT SYSTEM SITE MANUAL

W. L. Joosten
W. G. Gammill
E. D. Lee

June 1966
NAS 5-9125

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS
(Continued)

1.0 INTRODUCTION

The RADINT (SSD) system is capable of making trajectory measurements with great precision. This precision of measurement depends to a very large degree upon the precision with which the RADINT site is initially established and upon the care with which the site measurements are maintained.

Various system errors and tolerances on the site measurements have been explored and limits have been set. Most of this information appears in various papers which are available. Some of the tolerances have not been previously available except in unpublished notes and letters.

The purpose of this report is to present all the errors and tolerances in condensed form to aid site engineers in deciding on the acceptability of the site parameters at new sites and in maintaining necessary accuracy at old sites.

The basis for arriving at these tolerances is shown. Where the calculations and derivations have appeared previously, they have been abstracted or footnoted here in order to make this as self contained as possible.

Since sufficient literature predates this report, it is assumed that the reader has full familiarity with the system. Therefore, no attempt has been made to define special terms which are used.

In ANY case where the site engineer is in doubt about the sufficiency of a measurement, the value should be noted and reported so that computer correction can be made if later deemed necessary.

2.0 GENERAL

2.1 Speed of Light

The free space speed of light C_o was selected by J. C. Seddon (of NASA) based on the value used by BRL in early 4-Station DOVAP.

This is[1]

$$C_o = 983.57044 \times 10^6 \text{ feet/sec.}$$

Using 1 meter = 3.2808333 feet

$$C_o = 2.9979287 \times 10^8 \text{ meters/sec.}$$

(Physics handbooks also quote 983.571×10^6 feet/sec.)

2.2 Refractive Index

2.2.1 Atmospheric Refractive Index

In the presence of the atmosphere, the speed of light becomes

$$c_n = \frac{C_o}{n}$$

where $n = 1 + N \times 10^{-6}$

$N = N_D + N_W$ (Dry Term + Wet Term)

$$N = 77.6 \frac{P}{T} + 3733 \frac{RH\,(e_s)}{T^2}$$

where P = station atmospheric pressure in millibars

T = degrees K

RH = relative humidity

e_s = saturation vapor pressure at T

If the vapor pressure is not available[2] then

$$e_s = 6.105 \times 10^{\frac{7.5\,(T - 273)}{T - 35.7}}$$

The refractive index nomogram[3], Fig. 1, shows that values of n = 1.000236 to 1.000466 can be expected.

The value used in RADINT is a "nominal" value of 1.000288.

2.2.2 Ionospheric Refractive Index

The general equation for the ionospherics refractive index[12, 13], called the Appleton-Hartree equation can be shown to reduce to the plasma frequency term at 36 Mc and 73 Mc.

$$\mu = 1 - \frac{40.5\ Ne}{f^2}$$

where Ne is number of free electrons per cc

f is exploring frequency in Kilocycles.

Thus, in the ionosphere, the propagation velocity becomes, for C_o = vacuo speed of light.

$$C_i = C_o/\mu$$

and the ionospheric wavelength becomes

$$\lambda_i = \frac{1}{\mu} \lambda_o$$

2.3 Wavelength

The wavelength is $\frac{C_o}{NF}$, where F is the frequency and N is the index of refraction in the local medium where the wavelength is desired.

Where $F = f_o + \Delta f$, and $N = n_o + \Delta n$, then

$$\lambda = \frac{C_o}{(n_o + \Delta n)(f_o + \Delta f)}$$

In this case, f_o is the assumed center transmitted frequency, and Δf is the variation or difference between this and the actual frequency. Also $n_o = 1$ and Δn is the difference from unity.

Thus

$$\lambda = \lambda_o \left(1 - n - \frac{\Delta f}{f_o}\right)$$

where

$$\lambda_o = \frac{c}{f_o}$$

As shown in the section on index of refraction, $\Delta n = 28.82 \times 10^{-5}$ was chosen for nominal sea level correction.

The largest shift in F caused by Doppler is about 830 cycles for double path.

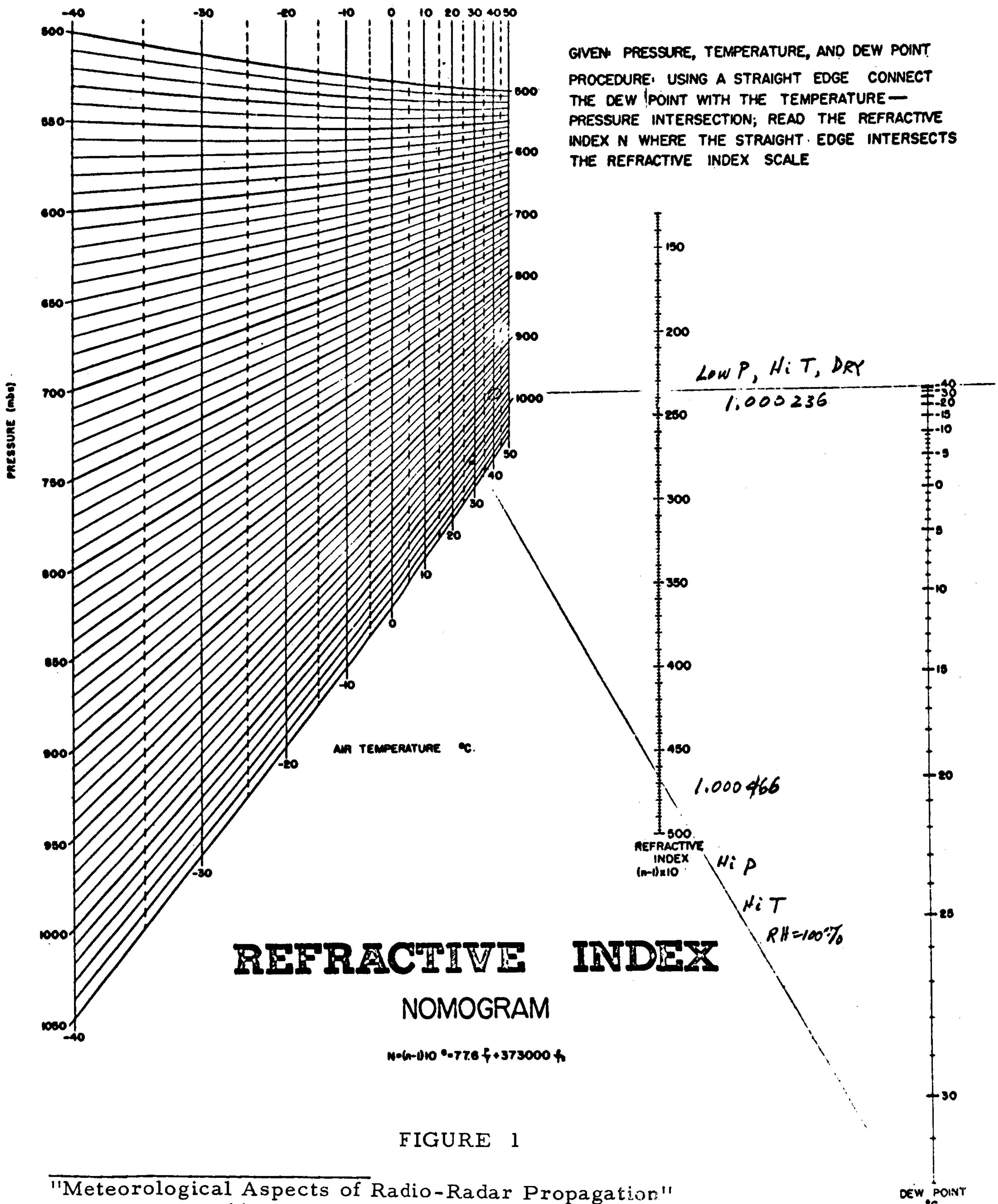


FIGURE 1

"Meteorological Aspects of Radio-Radar Propagation"
NWRF 31-0660-035

Thus

$$\frac{\Delta f}{f_o} = 1.1 \times 10^{-5}$$

For 73.6×10^6 cps

$$\lambda_o = 13.363729 \text{ feet}$$

or

$$\lambda_o = 4.0732727 \text{ meters}$$

$$\frac{\lambda_o}{4} = 3.340932 \text{ feet}$$

Since the system in "double path" mode effectively multiplies the Doppler by 4, the effective wavelength is

$$\lambda_{o4} = 1.018318 \text{ meters.}$$

The system in the "single path" mode effectively multiplies the Doppler by 2, thus the effective wavelength is

$$\lambda_{o2} = 2.036636 \text{ meters.}$$

The ground level wavelength, using N = 1.0002882 is

$$\lambda_n = 13.359879 \text{ feet.}$$

3.0 REFERENCE TRANSMITTER

3.1 Second Harmonic

The second harmonic from the reference transmitter has proven to be the most serious cause of system interference. This depends on weather conditions, range geometry, type of transmitter, etc.

Because of the very low post detection filtering applied, the analog "ROLL" channel provides a reliable visual check as well as a history of the second harmonic interference level.

With the transmitter turned on, and with all other sources of radiation turned off (crystal oscillators, transponder, signal generators), any second harmonic present at the Doppler antennas can be made to produce a synthetic roll output by driving either the RH or LH Doppler receiver with the 67.12 Mc ±1 cycle instead of the operating 67.12 Mc local oscillator signal.

If the synthetic roll signal thus generated approaches 10 percent of the full scale deflection of the roll channel, the system is considered to be approaching an undesirable second harmonic interference level (about -135 dbm).

It is of course most desirable that no synthetic roll be observed, at which time, second harmonic will be below -140 dbm to -145 dbm.

The decision as to the system go or no-go condition must be based on personnel experience, type of missile born experiment, data quality needed, difficulty of reducing second harmonic level, etc. (See ref. 4, p 50.)

The most reliable cure for second harmonic interference, which is used when all other attempts fail, is to put distance between the transmitting antenna and the receiving site.

3.2 Power Level

The radiated power from the reference transmitter is not critical. Operations have been conducted with as much as 4000 watts and as little as 80 watts. The higher power level is accompanied by more severe second harmonic problems. A 60-watt level, used on an emergency basis, produced severe drop-outs below 100 K feet on the trajectory down leg. This was caused by poor antenna aspect as well as low transmitter power. One transmitter has a nominal power level of 300 watts, with a maximum capability of 500 watts. A second type has a nominal level of 100 watts. When up leg trajectory data only is needed, the power can be less than 100 watts. Otherwise, the power level should be 100 watts or more.

3.3 Antenna

3.3.1 Types

The types of antennas which have been used are the helix (two models) and the circularly polarized turnstile. (See refs. 7, 8 and 9.)

3.3.2 Polarization

The reference transmitter antenna is always polarized RH-transmitting, regardless of antenna type. (See Appendex C.)

3.3.3 Circularity

The circularity is as important as that of the receiving antennas. The polarized turnstile has exhibited axial ratios (AR) 2 to 4 db on-axis, while the helix antennas have been measured from 3 to 4.5 db. The ellipticity should not exceed an AR of 6.0 db, with 3.0 db or less being considered satisfactory, and 1.0 db or less as excellent.

3.3.4 Location

The reference transmitter antenna location is not critical so long as it is surveyed to within about a foot. The requirements that must be met generally allow a choice of locations. From the standpoint of trajectory reduction, it is desirable to locate the antenna as near to the Doppler receiving antennas as possible. This is clearly impractical, however, because of second harmonic level. From experience, it has been found that 200 to 300 feet is the minimum tolerable distance. The direction from SSD is not important data reduction wise.

The maximum distance is set by the line of sight to the missile and to the RADINT Doppler antennas. It is necessary that a minimum signal of -90 dbm be received at the RADINT van, with -70 dbm or more being more desirable. Sufficient signal must be received at the launcher to give a good S/N at the transponder. The order of -70 dbm is satisfactory.

3.3.5 Orientation

The orientation of the transmitter antenna is unimportant. It has been found in practice, however, that some orientations are better than others in reducing second harmonic level at the RADINT van.

If low transmitter power is used, or if down leg trajectory data is important, it is acceptable to tilt the helix so that the beam points at about the peak of the trajectory. The tilt should not exceed more than 30 degrees from vertical. It is neither necessary nor desirable to tilt the polarized turnstile. The turnstile pattern is relatively broad, and tilting can affect the circularity.

4.0 INTERFEROMETER SYSTEM

4.1 Antennas

4.1.1 Circularity

The greatest source of phase error in the interferometer is caused by ellipticity of the antennas, both circular and linear.

If a circularly polarized antenna is not truly circular, then the pattern is said to be elliptical. This means that for a left-hand (LH) circular antenna, some right-hand (RH) signal is leaking through the antenna. If the leakage of the opposite polarity were at the same frequency as the desired circularity, no effect would be noted. However, this is not the case since the desired circularly polarized signal and the undesired opposite circularly polarized leakage are separated by a frequency equal to twice the roll rate (or spin frequency) of the missile. This separation frequency is generally, but not always, lower than the output filter cut-off frequency of the interferometer, with the result that the phase output of the interferometer has a ripple superimposed on it at twice the roll rate.

In Appendix A ellipticity and rejection relations are shown. For an antenna with 1 db of ellipticity, the leakage is down by -26 db below the desired signal. Thus, circular antennas used in this system should have no more than 1 db of ellipticity with 0.5 db of ellipticity being more desirable (leakage down by -35 db). Unfortunately, the circularity of an antenna is a function of signal arrival angle. For the lower elevation arrival angles, the leakage becomes much worse.

The present antennas have been measured at -35 db polarization separation. This means that a maximum phase ripple of two minutes of arc could appear on the interferometer data for vertical angles of signal arrival. This could be much worse at low elevation arrival angles.

It is always assumed that the transmitting antenna is purely linear. If the linear transmitting antenna has any ellipticity, then the two components of the linear signal (RH and LH) will not be of equal amplitude. If it happens that the larger component is received by the interferometer antenna, then the "system" circularity will be improved and phase error will be reduced. If the received component is the smaller, then the system circularity will be less than that of the receiving antenna above (See Appendix B.)

If the two antennas of an axis are not identically circular, then the phase from the two antennas will be slightly different as the missile spins in flight. This will show up as a ripple on the interferometer phase at twice the roll frequency.

When excessive ripple is noted on one axis, the two antennas concerned should be dismantled and visually inspected to see if the cause can be determined. If ripple is observed on both axes, then it is probably due to the missile antenna. If ripple is observed on different missile flights then the interferometer antennas should be suspected.

If the cause is not found visually, the antennas should be replaced one at a time by spares until the observed ripple is reduced to a more desirable level. The faulty antenna when found should be returned for complete overhaul or retained for use as spare parts only.

4.1.2 Polarization

The two antennas of an interferometer axis (i.e., N and S) must be polarized for like polarization. If this is not done, then as the missile spins, there will be a two-roll frequency superimposed on the interferometer pattern. This is caused by the right and left hand signals transmitted by the missile being separated by twice the roll frequency (See ref. 4, pp 57 and 66.)

The inductively phased interferometer antennas are normally operated in the LH receiving mode. In the northern magnetic hemisphere, this receives the ordinary mode of propagation from the missile. This mode makes the interferometer least sensitive to ionospheric disturbance or turbulence.

In the southern magnetic hemisphere (for example, the magnetic equator at 75° W long. is at 14° S latt.), the site engineer may choose to operate in the RH mode. If high altitude shots above 100 Km are intended, then RH operation in the southern hemisphere is more desirable to minimize ionospheric induced irregularities.

In Appendix C the connections for desired polarity are shown.

4.1.3 Coupling

When energy is absorbed by an antenna, half of the energy is transmitted to the load (assuming power match) and half is re-radiated into space. Any of the re-radiated power which reaches another interferometer antenna acts as an interfering signal.

This coupling represents one of the most serious sources of error in the interferometer.

Measurements have been made of coupling of the various antennas. The coupling was found to be a function of the trailer position in the array.

With the position as shown, the

N
X

DOPPLER
WX X XE

X
S

isolation was:

S to E	-65 db
E to W	-66 db
N to E	-51 db
N to W	-60 db
N to S	-68 db
N (LH) to Doppler (LH)	-45 db
N (LH) to Doppler (RH)	-53 db

Reflecting objects and other antennas inside or in the near vicinity of the interferometer which might enhance the coupling must be kept to a minimum (See ref. 4, p 53.)

The coupling is measured by radiating from one antenna and receiving at another antenna. The difference in signal is corrected for the various cable losses. The result is the coupling between the two antennas.

4.1.4 Impedance

The antennas are produced as nearly identical as possible, with no provision for adjusting impedance. The antennas are measured with one of the lead-in cables. The antennas are then selected in pairs which give the least difference in the reactive term as seen from the receiving end of the lead-in cable.

If a difference in the reactive term of a pair of antennas exists, then a phase error will exist in the interferometer[5]. The phase error will be 0.4 minutes of space arc for 1 pico-farad difference in the terminal reactance.

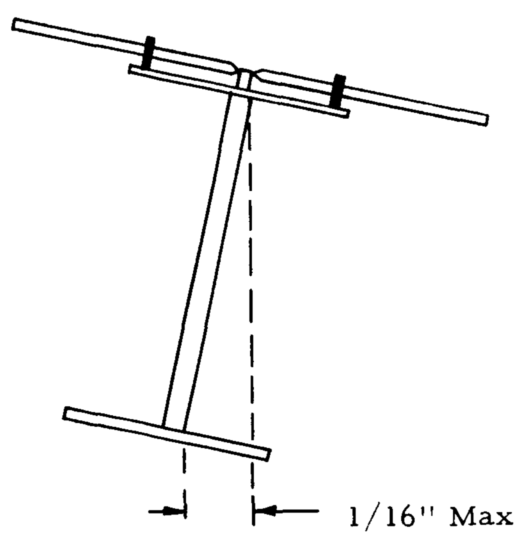
It is desirable that the reactive difference be no greater than 0.5 pico-farads, with 1 pf difference being the largest acceptable.

4.1.5 Element Tilt

If the phase center of the turnstile lies in the horizontal plane, but the elements themselves are tilted from this plane, generally insignificant errors are introduced in the interferometer(6). When the antenna balun is adjusted vertically as described, the elements will be positioned sufficiently and correctly in the horizontal plane.

4.1.6 Balun Plumb

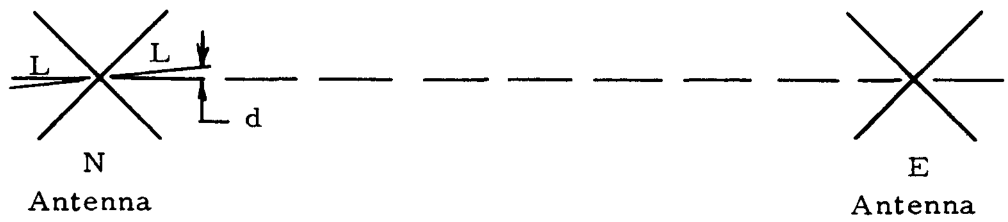
The antenna base plate is adjusted until the balun supporting the elements is no greater than 1/16 inch (0.005 feet) from vertical in any direction. This is accomplished with a carpenter's level.



4.1.7 Element Rotation

If the elements of one turnstile of an axis are not exactly aligned with the elements of the other turnstile of that axis, then the angular rotation of the two signals to the two antennas will have an error in electrical degrees equal to the angular difference between the alignment of the elements of the two antennas.

The rotational alignment sight (006830) is 43 inches long or 2 L long. If d is the deviation of the end of the sight (when used on an antenna of one axis) from a line connecting the phase center of the axis antenna and a non-axis antenna (i.e., N and E, etc.), then the error is 57.3 d/L electrical degrees. This assumes the other antenna of the axis is perfectly aligned.



The error in electrical degrees (per antenna) is 0.1 degrees electrical for d = 1/4 inch. It is desirable to rotate the antenna until d is less than 1/8 inch.

If the alignment sight has any minor misalignment error, this could produce error. This misalignment error cancels, however, if the N antenna is sighted on the E, and the S antenna is sighted on the W. Likewise, the E antenna is sighted on the S, and the W antenna is sighted on the N.

4.1.8 Axis Spacing

The spacing between the <u>phase center</u> (center of the terminal where the four elements are attached) of two antennas of an axis is theoretically 16.0 wavelengths.

Using the ground level wavelength, λ_n, this distance is 213.76 feet.

For an error of 1.0 inch (0.083 feet), the error in the slant plane zenith (lobe number = 0) is zero. At lobe number 2, the error is calculated:

$$\cos \theta = \frac{2.0}{213.76} \times \frac{213.76}{16} = 0.1250, \quad \theta = 82° \ 49.14'$$

$$\cos \theta = \frac{2.0}{213.84} \times \frac{213.76}{16} = 0.12495, \quad \theta = 82° \ 49.32'$$

The error at 2.0 lobes would be 0.18 minutes space arc.

Likewise at 8.0 lobes, the error would be 0.76 minutes.

At the horizon (16 lobes), the error would be 1.5 space degrees. Therefore, variations greater than 0.01 feet from 213.76 feet are undesirable. If such variations exist, the exact value must be ascertained so that computer corrections can be made.

Since the antenna vertical support balun is adjusted to within 0.005 feet of vertical by use of a carpenter's level, it is sufficient to measure the distance between the centers of the base of the antennas.

4.1.8.1 Tape Measurements

A steel tape is calibrated while it is lying perfectly flat with a tension of 20 pounds at 68° F.

Since field measurements rarely, if ever, are made under these conditions, it becomes necessary to establish a catenary sag by supporting both ends of the tape. Corrections are then made to the tape reading to obtain the true distance. The correctional procedure, for both ends of the tape at the same height, is found in any surveyors' handbook.

$$L_T = L_M + C_T + C_P - C_S + C_C$$

where

L_T = true distance
L_M = measured distance
C_T = temperature correction
C_P = tension (pull) correction
C_S = catenary (sag) correction
C_C = calibration correction = KL_M
$C_T = 6.5 \times 10^{-6} (T - T_o) L_M$

$$C_P = \frac{P - P_o}{AE} \quad L_M$$

$$C_S = \frac{W^2}{24\ P^2} \quad L_M^3$$

where

L_M, L_T are in feet
T = ambient temperature, deg. F
T_o = reference temperature = 68° F
P = tension on tape in pounds
P_o = reference tention = 20 lb
A = cross sectional area, square inches
E = elasticity $\gtrapprox 3 \times 10^7$ lbs/in^2
W = weight of tape in pounds/foot

For the Lufkin No. 1279DX, 300 foot tape,
$A = WL = 0.0135 \times 0.222 = 3 \times 10^{-3}$ in^2
$W = 1.01 \times 10^{-2}$ pounds/foot

Thus, for this tape:

$$L_T = L_M + 6.5 \times 10^{-6}(T-68)L_M + 1.1 \times 10^{-5}\ (P-20)L_M$$

$$4.25 \times 10^{-6}\ \frac{L_M^3}{P^2} + KL_M$$

4.1.9 Axis Bearing

If an error of 1 minute of arc is made in the alignment of the N-S axis with the true N-S axis, then angles mearsured E or W near the horizon will contain this one minute of arc error. This error in the N-S slant plane elevation angle reduces to zero at the true zenith (i.e., a vertical slant plane) and along the N-S axis.

A bearing survey error in the E-W axis will produce a like error in the N-S direction.

It is necessary to achieve 1 minute of arc accuracy in the alignment of the axes. Otherwise, the exact angle should be ascertained so that computer correction can be made.

4.1.10 Axis Tilt

4.1.10.1 Error limits

If the phase centers of the two antennas of one axis do not lie in the horizontal plane, then one antenna will be higher than the other. This effectively tilts the horizontal axis.

If the N-S axis is tilted by one minute of space arc, all slant plane elevation angles measured when the slant plane is vertical will contain this error (i.e., angles measured from the N horizon through true zenith to the S horizon). The error reduces to zero as the slant plane becomes horizontal E or W.

An E-W axis tilt will produce a like error in the E-W slant plane.

If the two antennas of an axis are adjusted to within ± 1/16 inch of the same height, the maximum axis tilt error is:

$$\pm \frac{1}{16} \text{ inch} = \pm 0.0052 \text{ feet}$$

$$\frac{\pm 0.0052}{214} \times 57.3 = \pm 0.0014 \text{ space degrees}$$

$$= \pm 0.083 \text{ minutes of space arc}$$

4.1.10.2 Surveying for tilt

A transit is used to survey the antennas to determine the level of one relative to the other. A point is chosen near the E (or W) antenna which is symmetrically located with respect to the N and S antennas. This symmetrical location eliminates any errors which might be caused by the transit calibration being in error. The transit table is leveled approximately. The transit telescope is aimed at the N antenna and the telescope bubble level is leveled as precisely as possible. The N antenna height is read off a ruler which is placed atop the N antenna. The transit telescope is then aimed at the S antenna, the telescope releveled and the S antenna height read. To rule out possibility of errors, the N antenna should be read a second time, followed by a second reading of the S antenna.

The procedure is then repeated for the E-W antennas.

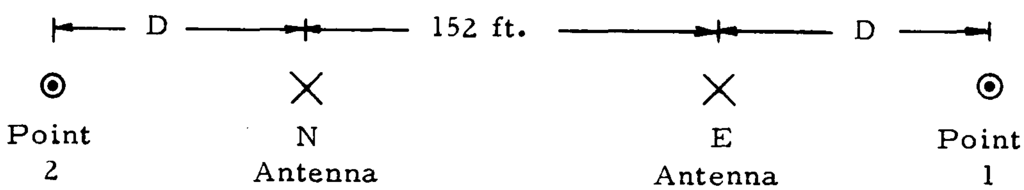
If it is undesirable for any reason to correct the antenna heights on site, the height differences should be reported so that computer correction can be made.

The level of the N-S axis as compared to the E-W axis is of little importance, since this usually is held within a few inches.

4.1.10.3 Transit calibration

Should it be necessary to calibrate the transit for level, the following procedure can be used.

Select two adjacent antennas (for example: N and E). Mark off two distances as shown in the figure. These distances should be 100 feet or more.



Set the transit at point 1, level carefully and read the E and N antenna heights, calling these readings E1 and N1. Set the transit at point 2 and read N2 and E2.

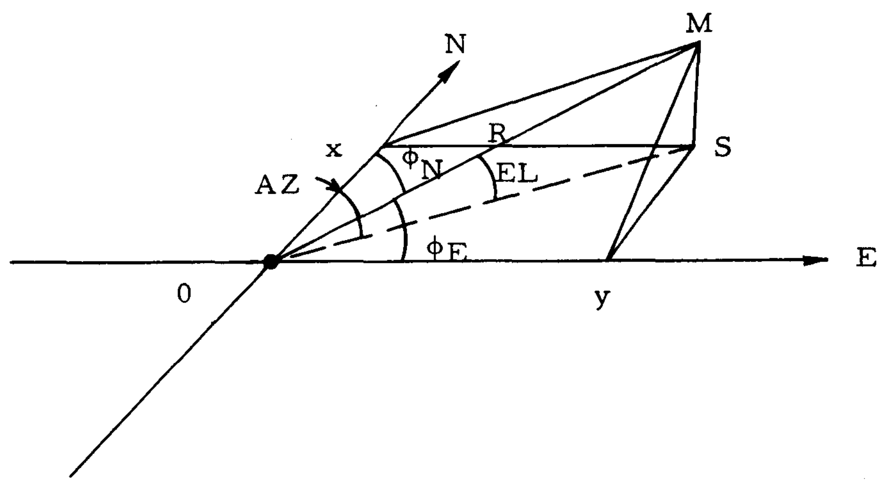
If the transit shoots below the level plane, then N1 will appear to be higher than E1, and E2 will appear higher than N2. Taking N1 - E1 and E2 - N2, the error (where D is in feet and the measured heights are in inches) is:

$$e = - \frac{\frac{1}{2}(N1 - E1 + E2 - N2)}{D} \quad \text{inches/foot}$$

If the transit shoots above the level plane, then E1 will appear to be higher than N1, N2 higher than E2, and the error will be:

$$e = + \frac{\frac{1}{2}(E1 - N1 + N2 - E2)}{D} \quad \text{inches/foot}$$

4.1.11 AZ, EL Readout



In the above figure, the origin is assumed to be the center point of the interferometer array, and the missile is at point M, a distance R from the origin. The direction angles are ϕ_E as measured from the "E" axis to R and ϕ_N as measured from the "N" axis to R.

The coordinates of the missile sub-point S become:

$$y = R \cos \phi_E$$
$$x = R \cos \phi_N$$

Note that in the N-E quadrant x is positive; y is positive; E-S quadrant, x is negative, y is positive; S-W quadrant, x is negative, y is negative; W-N quadrant, x is positive, y is negative.

The azimuth angle, measured from the North axis to the missile sub-point becomes:

$$AZ = \arc\tan \frac{y}{x}$$
$$AZ = \arc\tan \frac{\cos \phi_E}{\cos \phi_N}$$

but $\cos \phi_E = \frac{\delta_E}{d}$, $\cos \phi_N = \frac{\delta_N}{d}$, where δ_E and δ_N are the direction lobe numbers, d is the interferometer axis antenna spacing (nominally 16 wavelengths). Thus:

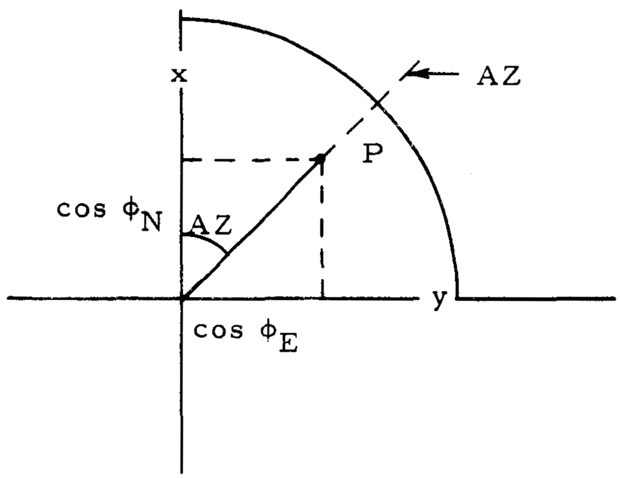
$$AZ = \text{arc tan} \frac{\delta_E}{\delta_N}$$

The elevation angle, measured from the horizontal plane (containing the missile sub-point) up to the missile is:

$$EL = \text{arc cos} \frac{\sqrt{x^2 + y^2}}{R}$$

$$= \text{arc cos} \sqrt{(\cos \phi_E)^2 + (\cos \phi_N)^2}$$

Where $\cos \phi_E$ and $\cos \phi_N$ are available as a d-c voltage, as from the interferometer Servo Tracking Filters, and are applied to an X-Y plotter, a special chart paper allows a graphical solution of AZ and EL, as shown below.



If $\cos \phi_N$ is applied to the x axis and $\cos \phi_E$ is applied to the y axis, and a pen deflection to point P is assumed, it can be seen that:

(a) The AZ angle will be read directly if a polar coordinate paper has 0 to 360 degree increments around its periphery.

(b) The distance from the origin to the point P is equal to $\sqrt{\cos^2 \phi_E + \cos^2 \phi_N}$, which is the cos EL. Thus, if the distances from the origin to the periphery are spaced according to the cosine function, the EL angle can be read directly from the graph at the point P.

4.2 Cables

4.2.1 Length

The four interferometer cables are initially cut to identical lengths (approximately 142 feet) from a single length of cable. The electrical lengths of the N, S, W and E cables are then cut to identical N half-waves by use of an rf bridge.

These cables operate essentially in the "flat line" mode since the receiver terminating impedance is adjusted to 50 ohms. If these cables are not equal in length, the electrical phase error is

$$\Delta\phi_c = 360 \frac{\Delta L}{\lambda C} \text{ electrical degrees,}$$

where ΔL is the difference in electrical length of a pair of cables.

The pair of cables which are connected to the antennas of an axis (i.e., N and S) are matched in length by a line stretcher prior to a firing.

With the antenna end of the cable open circuited, the receiving end measures about 160 ohms (due to cable loss). Any variation from an exact half-wavelength appears as a small reactance. Using the Boonton R-X meter, a pico-farad of parallel reactance is equivalent to 1.4 electrical degrees. The phase shifter is adjusted until the cables are within 0.05 pico-farads of each other, which means the difference in lengths is within 0.14 electrical degrees.

It should be noted that the cable lengths are set in the open circuited condition. A large standing wave exists along the cable. Any small variation in the line impedance somewhere in the line can produce a significant variation in its electrical length. This small impedance distrubance would have negligible effect when the line is operated in its flat line mode. Variations of two electrical degrees have been observed when a line was bruised by stepping on it. It is important that bruising of the interferometer cables be prevented.

4.2.2 Leakage

Cable to cable leakage in the interferometer can produce interfering signals. The use of rf double shielded,50 ohm cable provides isolations between cables of the order of 110 db[4].

The use of internal system double shielded cable and other shielding maintains isolations greater than -65 db.

It is necessary that such leakage never be greater than -60 db.

4.3 Receivers

4.3.1 Input Impedance

It is generally desirable[5] to set the imput impedance of the receivers to 50 ohms. This is not absolutely necessary, however.

As a general rule, the receiver input impedance can be easily adjusted to within 10 pf (on the R-X meter) to each other.

It is undesirable to have a VSWR of greater than 1.6 in any case.

The following conclusions are found in Ref. 5. The impedances are those seen at the junction.

Z_{AN} , north antenna $(R_{AN} \pm jX_{AN})$

Z_{AS} , south antenna $(R_{AS} \pm jX_{AS})$

Z_{RN} , north receiver $(R_{RN} \pm jX_{RN})$

Z_{RS} , south receiver $(R_{RS} \pm jX_{RS})$

Z_{PA} , power divider output $(R_{PA} \pm jX_{PA})$

When $Z_{AN} \equiv Z_{AS}$, regardless of the value of the antenna impedance, and $Z_{RN} \equiv Z_{RS}$, regardless of the value of the receiver impedance, then the phase error $\phi_E \equiv 0$.

When $Z_{AN} \equiv Z_{AS}$, $\neq$ Z_{PA}, and $Z_{RN} \neq Z_{RS}$, then $\phi_E =$ ±0.018 minutes of space arc per ohm difference in R_{RN} and R_{RS}. Also, $\phi_E = \pm 0.018$ minutes of space arc per ohm difference in X_{RN} and X_{RS}.

When $Z_{AN} \equiv Z_{AS} \equiv Z_{PA}$, then $\phi_E \equiv 0$ for all values of receiver input impedances. It is desirable to adjust Z_{PA} to approach this condition. (See 4.4.2.)

It was found that the phase error caused by antenna reactive differences could be reduced somewhat if the receiver reactances were not equal to each other. The table below illustrates this effect, which is relatively independent of the receiver resistive values.

X_{AN} Ohms	X_{AS} Ohms	X_{RN} Ohms	X_{RS} Ohms	ϕ_E Min. Sp. Arc
-5	-3	0	0	+0.8
-5	-3	+10	-10	+0.4
-5	-3	+20	0	+0.4
-3	-5	0	0	-0.8
-3	-5	-10	+10	-0.4
-3	-5	-20	0	-0.4

It has been shown that it is not necessary to adjust all impedances at the internal-external junction to precisely 50 ohms.

It has been found that simply setting the receiver input impedances to the same value is quite sufficient. The phase error has been found to be relatively independent of the receiver input impedances up to VSWR = 1.6. For example, a difference in the real part of the input impedances of 10 ohms and a difference in the input reactances of 20 ohms (about 18 pf) could contribute an error of as much as ± 0.54 minutes of space arc.

4.3.2 Phase Calibration

The RADINT interferometer receiver system, when properly tuned for maximum output, will generally operate from -70 dbm to -130 dbm in the range of ± 2Kc from fo with less than ± 2 electrical degrees differential phase shift.

The differential phase shift versus frequency difference from fo can be removed by touching up the tuning of the 465 Kc IF strip while sweeping the 73.6 Mc signal into both inputs of the receiver.

Phase shift calibration, as a rule, is not required.

When excessive phase shift is observed in the system caused by signal level or Doppler frequency to the receivers, a calibration should be run so that later correction for phase errors can be made.

The 73.6 Mc crystal oscillator is offset from center frequency by ΔF to simulate Dopper. The reference phase zero is set for a signal level of -95 dbm and $\Delta F = 0$. The receiver (N-S or E-W) which gives the greatest AVC swing should be used for AVC.

AVC and phase zero are recorded on the analog recorder for ΔF = +900 cps, +600 cps, +300 cps, 0cps, -300 cps, -600 cps and -900 cps for each signal level of -65, -75, -85, -95, -105, -115 and -125 dbm.

4.3.3 Sidebands

Sideband interference is more of a problem for the interferometer system than for the Doppler system because of the Doppler receiver selectivity. The sidebands become objectionable in the interferometer system below 10 Kc to 15 Kc. The same rule should be followed as in 5.2.2

4.4 Power Divider

4.4.1 Description

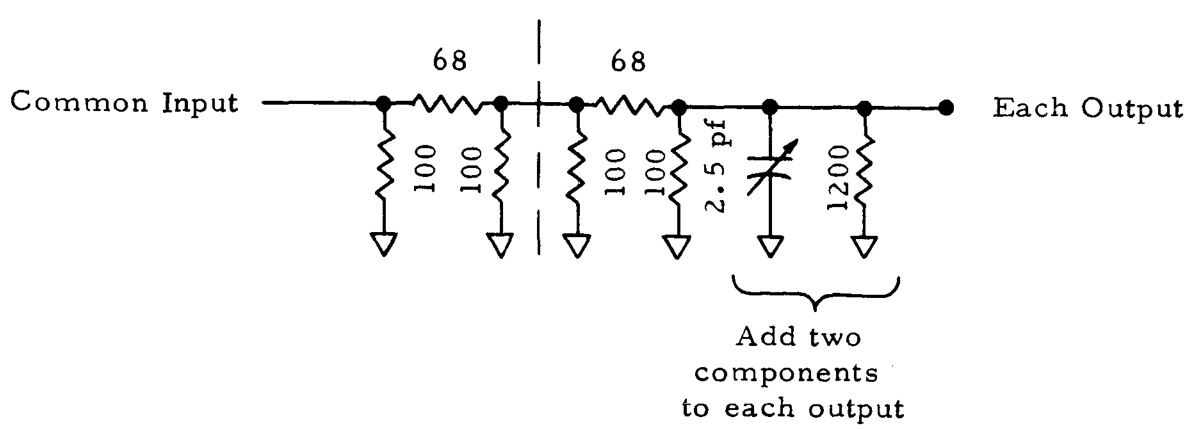
The power divider has two identical attenuators; each attenuator consists of two 10 db sections. The input impedance of the power divider is 50 ohms. The two outputs have identical impedances which closely approximate the antenna impedances.

The total attenuation between the two outputs is 46 db (with a 50 ohm signal generator connected to the input). However, since the signal is injected at the midpoint of the two attenuators, the effective isolation between the two outputs, signal to noise wise, is -26 db.

4.4.2 On Site Compensation

Reference 5 concludes that when the power divider output impedance is equal to the antenna impedance at the internal-external junction, the phase error caused by the receiver input impedances not being exactly 50 ohms is in all cases zero. It is desirable, therefore, but not mandatory, that the power divider outputs be slightly modified to present an impedance at the junction which is the nominal value of the on site measured antenna impedances. This procedure does much to minimize junction phase errors which are caused by the receiver input impedances being non-identical.

For example; suppose Z_{AN} = 47 ohms, +3 pf; Z_{AS} = 49 ohms, +2 pf. Then Z_{PA} should be tailored to Z_{PA} = 48 ohms, + 2.5 pf. This is done by adding two components to each power divider output as shown below.



4.4.3 Calibration

The power divider phase shift through the two attenuator legs must be identical.

The two power divider outputs are connected to the two receiver inputs; and a signal of -70 dbm is applied to the power divider input (this is about -95 dbm to each receiver).

The phase zero position of the interferometer phase detector is noted. The two power divider outputs are then reversed and connected to the receivers.

Any difference noted when reversing the connections is compensated for by adding a small capacitor (generally in the 1 pf to 3 pf range) to the appropriate attenuator (found experimentally). The capacitor is added between the two 10 db sections of the attenuator.

The difference in phase observed in the reversing test should not exceed 0.5 electrical degrees.

4.5 Miscellaneous

4.5.1 Frequency Shift

Due to the Doppler shift, the spacing "d" of the antennas in wavelengths varies.

From the equation $\cos \phi_0 = \frac{\delta}{d}$, the maximum variation in the ϕ_o of about 0.3 space drgrees for a 2 Kc shift in the 73.6 Mc signal is found to exist along the interferometer axis. The error reduces to six seconds space arc (0.1 minutes) at 45° slant plane angle and to zero at the slant plane zenith.

A 2 Kc variation in 73.6 Mc is equal to about 3 parts in 10^5 variation in the frequency. In general, the Doppler shift effect on the interferometer can be neglected.

Likewise frequency variations as high as 1 part in 10^5 have no serious effect on the interferometer accuracy.

4.5.2 Parallax

If the source is not far removed from the center of the array, then a parallax error exists between the apparent direction of the center of the axis to the source and the true line of sight direction. (See ref. 4, p 36.)

This parallax error as a function of range distance and true bearing angle is shown graphically on the following page.

4.5.3 Index of Refraction

As shown in 4.1.8 and 2.2, the spacing between antenna phase centers is selected on the basis of a nominal n = 1.0002882.

The angular errors in the interferometer (minutes of space arc) caused by other than nominal index of refraction is shown below. The index of 1.0002 is for a hot, dry desert atmosphere, while 1.0005 is used for a cold, foggy coastal atmosphere.

		Error	
Lobe Number	Direction Angle	n = 1.0002	N = 1.0005
0	90	0	0
4	76	- 0.1	+ 0.1
8	60	- 0.2	+ 0.4
12	42	- 0.4	+ 0.8
16	0	-48.0	+68.0

4.5.4 Space Angle Equivalents

A lobe contains 360 electrical degrees. One electrical degree is 1/360 = 0.0027778 lobes. Dividing the lobe number by 16,

$$\cos = \frac{\delta}{16} \quad \frac{0.0027778}{16} = 0.000173$$

From a trig table, this fraction of a lobe is equivalent to 0.6 minutes of space arc at zenith (i.e., $\theta = 90°$). Table 1 shows the relation for other than zenith angles.

Likewise, a trig table shows that a direction cosine of 0.0001 gives 0.35 minutes of space arc at slant plane zenith. Multiplying the minutes of space arc in this table by 0.6 gives the minutes of space arc for 0.0001 change in direction cosine.

Table 1 shows the direction cosine and space angle for the lobe numbers, based on a spacing of 16 λ_n = 213.76 feet.

4.5.5 Interference

When an interfering signal is received at an interferometer antenna, along with the desired signal, a phase shift can be produced in the

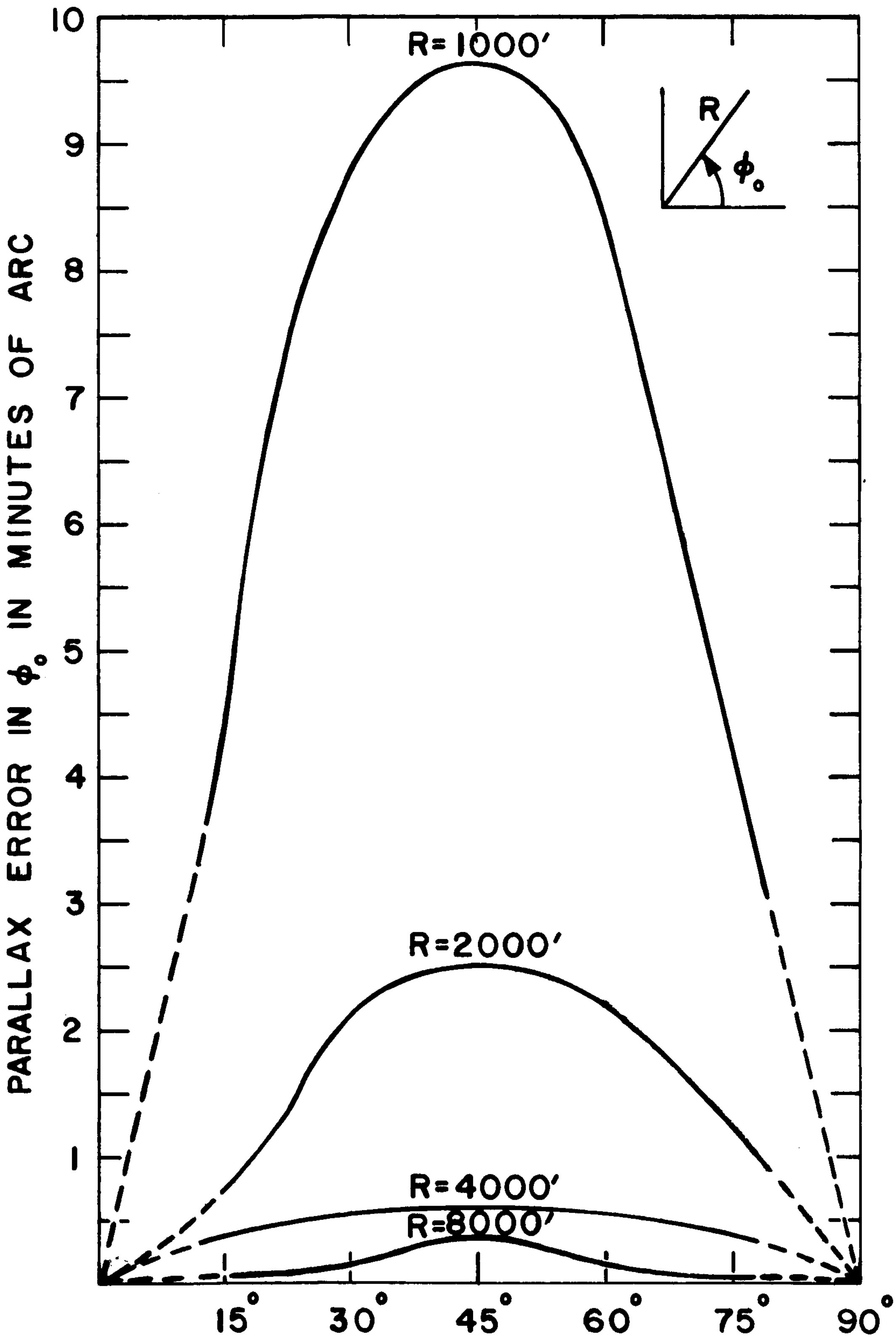


FIG. 2 - INTERFEROMETER PARALLAX ERROR

Lobe No. E-W	Lobe No. N-S	Direction Cosine	Direction Angle Space Degrees	Space Degrees Per Lobe	Min of Space Arc per Electrical Phase Degree	Min of Space Arc per 0.0001 in Dir. Cos.	Min of Space Arc per pf of Reactance
16E	16N	0.9999	Horizon	20.37	3.39	1.95	50 ohm nominal resistive component at 73.6 Mc
15E	15N	0.9375	20.37	8.58	1.43	0.82	
14E	14N	0.8750	28.95	6.71	1.12	0.64	
13E	13N	0.8125	35.66	5.73	0.96	0.55	
12E	12N	0.7500	41.39	5.18	0.86	0.50	
11E	11N	0.6875	46.57	4.75	0.79	0.46	
10E	10N	0.6250	51.32	4.45	0.74	0.43	
9E	9N	0.5625	55.77	4.23	0.70	0.41	
8E	8N	0.5000	60.00	4.06	0.68	0.39	
7E	7N	0.4375	64.06	3.92	0.65	0.38	
6E	6N	0.3750	67.98	3.81	0.62	0.37	
5E	5N	0.3125	71.79	3.73	0.62	0.36	
4E	4N	0.2500	75.52	3.68	0.61	0.35	0.8
3E	3N	0.1875	79.20	3.62	0.60	0.35	0.8
2E	2N	0.1250	82.82	3.60	0.60	0.35	0.8
1E	1N	0.0625	86.42	3.58	0.60	0.34	0.8
0	0	0.0000	Zenith	-	-	-	
1W	1S	-0.0625	93.58	3.58	0.60	0.34	0.8
2W	2S	-0.1250	97.18	3.60	0.60	0.35	0.8
3W	3S	-0.1875	100.80	3.62	0.60	0.35	0.8
4W	4S	-0.2500	104.48	3.68	0.61	0.35	0.8
5W	5S	-0.3125	108.21	3.73	0.62	0.36	
6W	6S	-0.3750	112.02	3.81	0.62	0.37	
7W	7S	-0.4375	115.94	3.92	0.65	0.38	
8W	8S	-0.5000	120.00	4.06	0.68	0.39	
9W	9S	-0.5625	124.23	4.23	0.70	0.41	
10W	10S	-0.6250	128.68	4.45	0.74	0.43	
11W	11S	-0.6875	133.43	4.75	0.79	0.46	
12W	12S	-0.7500	138.61	5.18	0.86	0.50	
13W	13S	-0.8125	144.34	5.73	0.96	0.55	
14W	14S	-0.8750	151.05	6.71	1.12	0.64	
15W	15S	-0.9375	159.63	8.58	1.43	0.82	
16W	16S	-0.9999	Horizon	20.37	3.39	1.95	

desired signal. (See ref. 4, p 48.)

The direction and magnitude of the resultant phase shift cannot be determined. The effect on the system can only be calculated in terms of the maximum error which could be caused by the interfering signal. Thus, this sets an "indeterminate" region of phase error. The actual phase error can be less than the maximum, but the exact value is unknown.

The maximum interferometer error which can be produced by an interfering signal is shown below as a function of the interference to signal ratio (R).

R (db)	Error (Electrical Degrees)
-10	± 36.8
-20	± 11.5
-30	± 3.7
-40	± 1.2
-50	± 0.37
-60	± 0.12

The error in minutes of space arc can be determined from the electrical degree to space angle conversion table, Section 4.5.4.

It can be seen that interfering signals greater than -50 db compared to the desired signal are to be avoided. Interference of -60 db and below are of no real concern.

Also see Section 3.1.

5.0 DOPPLER SYSTEM

5.1 Antennas

5.1.1 Circularity

The leakage caused by noncircular antennas is generally less than -25 db. This leakage appears as a low frequency phase modulation of the desired signal which is carried through to the Doppler signal. On axis AR of 2.0 db or less is desirable.

Single Path operation with elliptically polarized missile antennas is covered in Appendix B.

5.1.2 Polarization

The automatic roll correction requires a knowledge of both the RH and LH portions of the linear wave transmitted by the missile. Therefore, an RH and LH polarized antenna is required. It is desirable to maintain circular polarization over as much of the receiving hemisphere as possible, so that proper roll correction is achieved over as much of the trajectory as possible. Refer to Appendix C for proper circular polarity.

5.1.3 Impedance

When dual Doppler antennas are used, one RH and one LH, their terminal impedance is unimportant so long as a reasonably good VSWR is obtained. For this reason, the turnstiles used for Doppler are those which are unsatisfactory for interferometer purposes.

When the single crossed dipole Magic Tee is used, the circularity is quite sensitive to the impedances terminating the Magic Tee and a special setup procedure is required. (See ref. 4, p 153.)

5.1.4 Location and Position

The dual Doppler turnstile location is unimportant so long as both turnstiles cause minimum interference with the interferometer antennas. The location atop the van roof has been found to be quite suitable. It is desirable to locate them about 2 wavelengths apart, but one wavelength spacing (13 feet) is acceptable. If possible, the dual turnstiles should be on a line perpendicular to the plane of the missile trajectory. This helps reduce the error in the Doppler caused by the interferometer effect due to the spacing. Since this error can amount to no more than six feet, however, this is relatively unimportant.

5.1.5 Coupling

The coupling between the RH and LH Doppler turnstile has been found to be -30 db for one wavelength spacing and -40 db for two wavelength spacing. Since this coupling is below the normal self leakage of the polarized turnstile (-25 db), this coupling has little effect on the Doppler data.

Coupling of RH and LH Doppler helix antennas has been found to be -40 db and -45 db for one and two wavelength spacing. The spacing between helix antennas is not critical.

5.1.6 Reference

The reference receiving antenna found most acceptable is a vertical stub, or wire, located where it is most convenient. The only requirement is that locations which produce significant coupling to all other antennas should be avoided.

5.1.7 Cables

The cable lengths to the dual Doppler and reference receiving antennas are unimportant. Radio frequency coupling between these cables should be avoided.

The cable lengths for the Magic Tee System are most critical. (See ref. 4, p 153.)

5.2 Receivers

5.2.1 Input Impedance

When using dual Doppler turnstiles, the receiver input impedance is unimportant, so long as a reasonable VSWR is obtained. It is generally sufficient to adjust the input impedance to 50 ohms in initially setting up the system. Checks should be made once or twice yearly afterwards to ensure that no malfunction has occurred.

The use of the Magic Tee requires that the receiver input impedances be matched to the Magic Tee.

5.2.2 Sideband Interference

Although they are not a severe problem, modulations of the carrier which produce sidebands below 15 Kc should be avoided. Sidebands below 10 Kc can cause occasional objectionable interference.

5.2.3 Phase Shift

The difference in the phase shift of two Doppler receivers has been consistently measured as ± 10 electrical degrees for a ± 2 Kc shift from center frequency. Since the Doppler range error produced by this phase shift is less than ± 0.15 meters, this differential phase shift is ignored.

5.3 Interference

5.3.1 Internal

Internal leakage causes were examined in detail. (See ref. 4, p 61.) The internal leakage should not be more than -25 db. If such is the case, the cause should be found and corrected.

5.3.2 Second Harmonic

Refer to Section 3.1.

5.4 Double Path System Test

If the RH and LH receivers are mis-connected, then an 8 roll error can be induced in the Doppler frequency. (See ref. 4, p 59.)

The following test will show if such a mis-connection has been made.

5.4.1 Connect 36.8, 73.6 Crystal Oscillator to reference receiver (36.8) and LH and RH receivers (73.6).

(If sufficient second harmonic from the reference transmitter exists, this could be used in place of the 36 - 73 Crystal Oscillator).

5.4.2 Connect 67.12 ± 1 to LH receiver.

5.4.3 Disconnect 480 Kc to 15 Kc output from RH receiver.

5.4.4 Lock tracking filters.

5.4.5 Doppler synthesizer Doppler output must be 3 times the Roll output frequency, monitored on scope or Sanborn recorder.

5.4.6 NOTE: The above test does not aid in determining that the dual Doppler turnstiles are properly connected, nor that the transmitting antenna is polarized for RH transmission.

6.0 RECORDER FORMATS

6.1 Sanborn Analog Format*

The format for the interferometer on the 6 channel Sanborn should be as follows. If recorder instability is encountered, then the E-W and N-S should be recorded on channels having the best d-c stability.

---

*Memo dated 6 November 1964, John Weinreich

Left Side

CHANNEL

←

1	2	3	4	5	6
GMT Range Code (when available)	2 Roll or other data	N-S Phase N Sense	E-W Phase E Sense	SSD Time	AGC (when needed)

6.2 Brush Mark 200 Analog Format

Left Side

CHANNEL

←

	81	82	45	46	47	48	
Left-hand marker SSD-time	80 MM N-S Phase N Sense	80 MM E-W Phase E Sense	40 MM TM or AGC (when needed)	40 MM Two Roll (if both TM and AGC are needed and no other recorder is available record TM here and obtain roll by playback)	40 MM Blank Channel	40 MM Blank Channel	GMT range code (when available)

6.3 Record Annotation

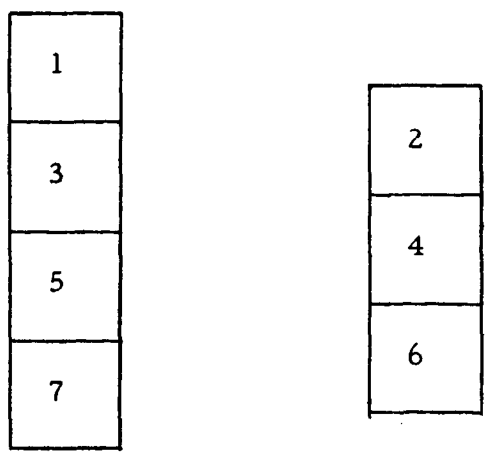
When in doubt as to whether any information should be annotated on the record, the rule is "mark the record." It is easy when doing data reduction at a much later date to ignore the markings. It is not so easy to remember some bit of data that is not marked on the record.

The record should be marked to show:

(a) Channel data allocation
(b) Approximate time of launch and missile number
(c) Phase zero calibration for AGC and frequency, when needed
(d) Approximate launcher setting, AZ and EL
(e) Any other items concerning the operations.

6.4 CEC VR-2800 Tape Format

The CEC VR-2800 is a seven track machine. There are two sets of heads as shown below.



To obtain the best performance from the machine, it has been found desirable to record related data on each head set.

The track allocations are:

TRACK	DATA
1	LH 15 Kc and Voice VCO
3	3 x LH 15 Kc - 2 x Ref 15 Kc
5	10 Kc + 1 per Time
7	RH 15 Kc
2	N-S 500 + ϕ
4	Ref 500
6	E-W 500 + ϕ

The normal record head drive level is 30 millivolts peak to peak across the record head current monitoring resistor (with no bias signal present). It has been found, however, that quite good results are obtained with 35 to 40 millivolts peak to peak.

Another method has also been found to work quite well. Adjust the playback amplifier gain to maximum output. Increase the record gain until the playback output limits (generally about ten volts peak to peak). Reduce the record level until the playback level is 70 to 80 percent of the maximum.

6.5 Viking 95 Tape Format

The Viking 95 is a four track machine used in the original SSD station.

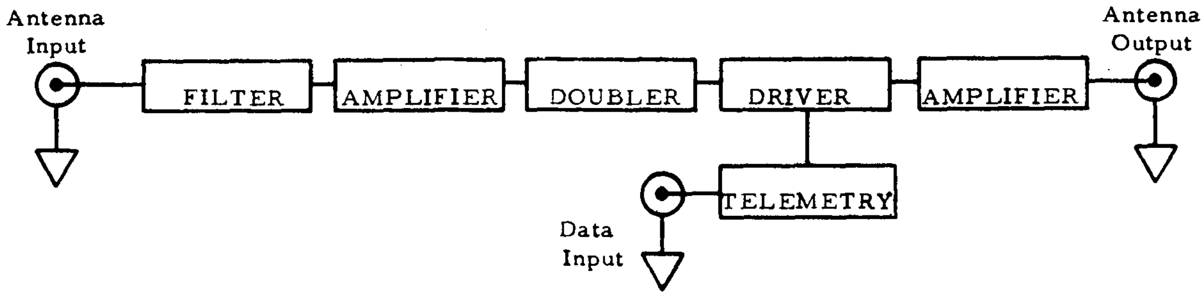
TRACK	DATA
1	LH 15 Kc
2	3 x LH 15 Kc - 2 x Ref 15 Kc
3	10 Kc + 1 per Time
4	RH 15 Kc

7.0 MISSILE INSTRUMENTATION

7.1 Airborne Transponder

7.1.1 General

The present UDT-B transponder is capable of 1.4 watts nominal output matched into a 50-ohm load, amplitude modulated by a 30 Kc subcarrier which provides a single channel of telemetry information. (See Photographs A and B.) As of March 1966, the UDT-B is the best example of an "off-the-shelf" flyable transponder. The diameter is approximately 5 inches; the height is 5-1/2 inches. A block diagram of the UDT-B is shown below.



A low-current, 6-volt latching relay is used for switching to external power or to internal power as desired. (See Photograph C.)

The transponders are shipped without the batteries which are to be prepared by the user; these batteries are a specific type. (See BATTERY PREPARATION.)

Mounted in the top plate of the transponder are BNC connectors for TM input, rf input and output, and a Winchester connector (CR5-2P-R) for power, monitoring and control wiring. (See Photograph A.) The pin connections are as follows.

Pin No.	Function
A	5.6-volt monitor
B	meter return
C	power return
D	250-volt monitor
E	external power (positive 5.8-volts)
F	battery charging
H	internal-external switching

7.1.2 Inspection

It has been requested that certain modifications be made at ITT LABORATORIES and these should be checked.

(a) Pin B grounded to the case; this is the meter return.

(b) A 100 ohm, 1/2-watt resistor in series with Pin A in the 5.6-volt monitoring circuit; this provides protection for the transponder from monitoring malfunctions.

(c) A 270,000 ohm, 1/2-watt resistor in series with Pin D in the 250-volt monitoring circuit; this provides protection for the transponder from monitoring malfunctions.

These should be corrected if found deficient.

Remove the bolts on the top side of the rf deck and the bolt through the center of the rf deck and the top plate. (See Photograph D.) Pull off the rf deck and inspect each stage for unsoldered or broken connections and connections that may be too close together. Correct any connections that appear suspicious. Check inside the rf deck for loose metal particles and remove if found. Replace the rf deck and replace the bolts. Be certain that the bolts are adequately tight.

Check the remainder of the transponder for anything suspicious and incorrect. (See Photograph B for subcarrier location.)

7.1.3 Battery Installation

Install the four batteries in their holder so that the negative terminal side is the first side to be inserted into the transponder. The negative terminal must be pointed to the center of the narrow side of the pack, or the terminal will obstruct the insertion of the pack into the transponder. A drop of Duco cement, Glyptol, or Loctite is placed on each tightened nut of the batteries. A length of electrical tape should be placed across the top rows of battery terminals before the pack is inserted into the transponder. (See Photograph E for battery pack without tape.)

7.1.4 RF Section Test

Connect a power monitor and a 50 ohm load to the rf output and a 25 uvolt, 36.8 Mc signal to the input. Connect the power and control plug and the TM signal. Transponder check-out on the bench can be performed with any variable d-c voltage source from 0 to 6 volts with a current capability of 6 amps. Apply d-c power gradually so no more than

5 amperes is drawn from the power supply and until 5.8 volts is reached. When the transponder has warmed, input signal has been applied, and the external power voltage has reached 5.8 volts, the transponder may draw between 4.5 and 5.5 amperes. Allow the transponder to warm-up for approximately 15 minutes in the transponder container. Checking the power output every 5 minutes will, mainly, indicate the power output stability of the last stage.

When the d-c supply current ceases to change, switch to internal batteries and note the battery voltage accurately on the monitor meter approximately 15 seconds after switching to internal; then, return to external power. Set the external power supply to this observed internal voltage.

Check the stability of the whole unit by reducing the input signal amplitude and observing the output. The output should decrease to zero when the input is reduced to minimum and the rf input cable has been disconnected. If the output power is the acceptable minimum or more (1.1 watts) with rf input of 20 uvolt, proceed to the SUBCARRIER OSCILLATOR. If the output power is low, the condition must be corrected. The usual method is by tuning. If the condition cannot be corrected by tuning, substitute another transponder. If none is available, repair the defective unit. Repair is generally accomplished by tube substitutions.

7.1.5 Subcarrier Oscillator Test

This check should be performed as close to "in-the-can" temperature condition as possible because the VCO is temperature sensitive. It is suggested that this be done at the end of the 15 minute initial warming period. The subcarrier oscillator is set for 30 Kc plus and minus 15 percent for a telemetry input between 0 and 5 volts positive. The high side is adjusted by applying 0 volts to the telemetry input and adjusting the 5 K ohm variable resistor until the oscillator frequency is between 34.5 and 34.4 Kc. The lower band edge is set 25.5 to 25.6 Kc by feeding 5 v d-c into the telemetry input and adjusting the 500 K ohm variable resistor. Repeat these adjustments. The subcarrier oscillator is checked for linearity by feeding zero to 5 v d-c, in one-volt steps, into the telemetry input. Plotting d-c volts input against frequency output should indicate good linearity so that no point will lie more than 500 cycles per second from a mean straight line drawn through the plotted points. (See Photograph B for the variable resistor locations.)

7.1.6 Container Modification

In the top edge of the transponder container, cut two rectangular notches 180 degrees apart, 1 inch wide and 1/2 inch deep. This modification is made for the holddown ring. (See Photograph A.)

This container must have a thin film of the silicon lubricant applied in the area of the top "0" ring to maintain internal pressure while the transponder is in the upper atmosphere. This lubricant is generally applied just prior to the final transponder installation in the payload can.

7.1.7 Battery Preparation

Yardney battery type HR-3 d-c must be used because of its its voltage plateau characteristic.

Prepare enough silver cell batteries to supply all missiles to be fired in a two week period; 1 flight pack per missile, 1 test pack, and 1 spare pack. Each pack contains 4 silver cells. Silver cells that have been prepared for more than a month should not be used in flight packs.

Battery preparation should be followed as outlined in the Yardney procedure. A copy is located at each site.

Briefly, the silver cells are filled with the accompanying premeasured electrolyte and set to soak for 36 hours inclined at approximately 30 degrees. At the end of this soaking period the batteries are turned over and allowed to soak for another 36 hours. The 30-degree angle is measured from vertical and the batteries are tilted on their narrow edge.

Observe precautions when handling electrolyte; the solution is basic and poisonous.

A lead time of 72 hours before missile assembly is required for proper battery preparation.

7.2 Shroud Antenna

7.2.1 General

The antennas should be checked physically and electrically before shipment to launch sites. These antennas should be shipped without silicon grease in the tuning section of the antennas and with adequate protection for the somewhat vulnerable pin connector and inductor tuning shaft. Two spare sets should be on hand at the launch site; this figure is modified by experience. Usually, time will not permit more than a few disassemblies and repairs; a replacement is quicker. A complete disassembly is required when one or more of the four antennas is found to be defective or inadequate.

A basic set of antennas for each missile consists of the following parts.

(a)	73.6 Mc, plus and minus (matched pair)	1 pair
(b)	36.88 Mc, plus and minus (matched pair)	1 set
(c)	teflon plug	4 each
(d)	stainless steel missile clamp or band	6 each
(e)	stainless steel coaxial cable clip	4 each
(f)	shock wave coupler	4 each
(g)	No. 7 teflon sleeving	10 feet
(h)	50 ohm copper coaxial cable	10 feet
(i)	L-matching network section assembly	1 each
(j)	misc: Glyptol, DUCO, or Loctite and Nos. 12 and 16 teflon sleeving	

Generally, lead time considerations become necessary or desirable depending upon the situation.

A set of shroud antennas usually can be installed and tuned in 4 to 8 man hours, depending on experience and troubles encountered.

If the rocket motor is not available, steps 7.2.2.1 (a) - (e) may be completed in preparation for antenna installation.

Also, full preparation of transponders can be accomplished prior to antenna installation and test equipment set up for antenna tuning.

7.2.2 Grenade Payload

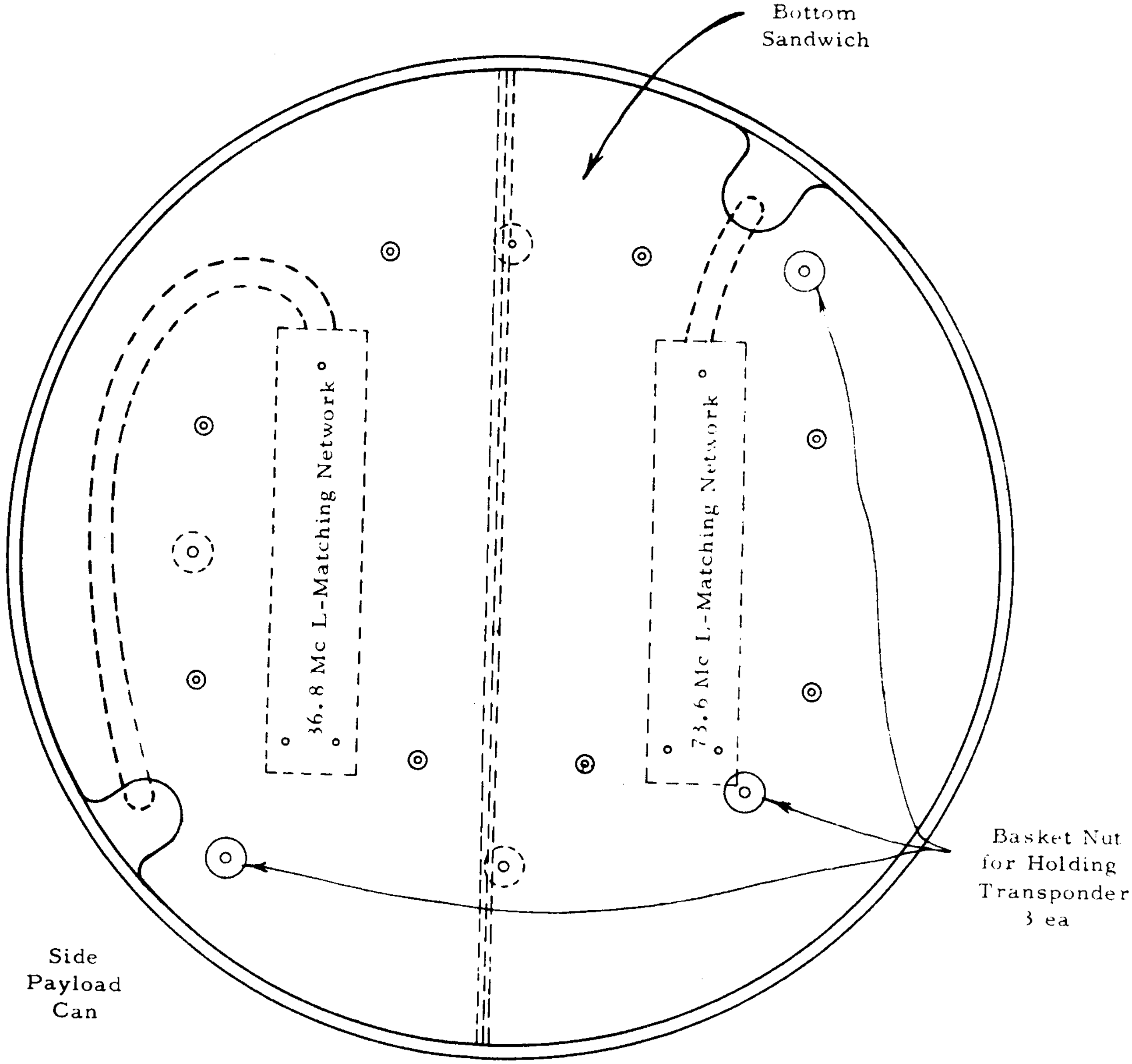
7.2.2.1 Sandwich assembly

(a) Remove the ''sandwich'' top plate by unscrewing the eight 4/40 flathead bolts, leaving the matching networks and the one inch standoffs fastened to the bottom plate. Set aside the top plate which is in two pieces.

(b) Mount the ''sandwich'' bottom plate in the bottom of the payload can with the four 6/32 bolts.

(c) Installation of the four copper coaxial lines will require alternating the types of bends so that the 36.8 Mc lines will have one of each style bend and the same with the 73.6 Mc lines. Mark the cable exit holes on the outside of the payload can so that the antennas of proper frequency will line up with the proper lines. (See Photograph F.)

(d) Cut four pieces of copper coaxial to equal lengths approximately 18 inches long.


Bottom
Sandwich
36.8 Mc L-Matching Network
73.6 Mc L-Matching Network
Basket Nut
for Holding
Transponder
3 ea
Side
Payload
Can

(e) Bend two of these cables on one jig board and the other two on the other jig board. (See Photograph G.)

(f) Installation of copper coaxial may be done now or after the payload can is locked in place on the motor. This decision is the result of personal experience. After the copper coaxial cables have been installed in the proper networks, lay one-half of the "sandwich" top plate in place. Do not secure until both halves of the top plate are in the payload can and centered properly.

(g) Slide a length of # 7 teflon sleeving over the copper coaxial so that approximately one inch extends into the payload can with the other end properly flush against the coupler. This sleeving provides ablative material for heat protection of the copper coaxial. Both "sandwich" plates (top and bottom) are marked "UMB" and this mark should be aligned with the center line of the umbilical hole.

(h) The fiberglass cables from the L-matching networks to the transponder fit through the top plates at the notches as shown in Photograph F. The cables should be marked with the proper frequency.

(i) For the final positioning of the connector location of the transponder in the payload can, refer to Photograph H.

(j) Remember, when the copper coaxial lines are trimmed to mate to the shockwave coupler, equal amounts of any pair of one frequency must be removed.

7.2.2.2 Antenna assembly

(a) Remove the phenolic cover from underside of the 73 Mc antennas and fill with silicon lubricant such as Dow Corning D-4. Replace the cover. (See Photograph I.)

(b) Inspect and if necessary, remove excess solder from the antenna pin connectors. Slip #7 teflon sleeving over the antenna coaxial lines to a point approximately one inch behind and under the fiberglass point of the antennas. Cut the sleeving flush with the tip of the pin connectors; this provides some protection during handling and during attachment to rocket motor.

(c) Insert the four stainless steel missile clamping bands under the stainless steel feet of each antenna; bend the feet to aid in holding the band in place, starting with the one particular antenna which has four screwdriver holes in the fiberglass.

(d) Disassemble four shockwave couplers, marking the top and bottom parts of the original mating to aid rematching of parts. Do not disassemble clamp-holding channel on the bottom of the couplers.

(e) The rocket motor must have four equidistant lines accurately marked parallel to the longitudinal axis and aligned with the cable holes in the payload can. One line should extend to the rear sufficiently to allow close setting and locking of the fins. These four lines are drawn only after the payload can is firmly attached to rocket motor. The lines are usually positioned with a marking stand using a plumb bob, but any suitable method is satisfactory. (See Photograph J.)

The guide line lines and, consequently, antenna placement must be orthogonal within 1/16 of an inch or antenna tuning is adversely affected.

(f) Position the four antennas with the four clamps so that the proper antenna is aligned with each coaxial cable exit hold and the front tips of the fiberglass shroud are approximately 12 inches behind the rearward side of the head cap. Align the antennas on the four orthogonal lines and equidistant from the headcap carefully and tighten the clamps.

(g) Thread the clamp through four shockwave couplers and install in position on the motor. The distance from the head cap is approximately 4 inches. Position these couplers so that equal holding action is provided for both pieces of copper coaxial. These couplers provide a convenient coaxial connection, mechanical support, and a shockwave device. (See Photograph K.)

(h) Bend the coaxial lines exiting from the payload can so that the lines are positioned over the channel in the couplers. (See Photograph L.)

(i) Observe how much slack and play is present in each line and cut the coaxial lines so that 3/16 of an inch of center conductor is available for insertion into the pin receptable. Remember, equal amounts of copper coaxial must be removed from each of the two lines of each pair. Example: 36 Mc pair of lines may be cut 3 inches but the 73 Mc pair of lines may only require 2 inches to be removed.

(j) Trim the teflon sleeving to terminate flush with edge of coupler.

(k) Mate pin and receptable and attach top part of coupler with two bolts. Do not solder connections at this time. (See Photograph M.)

(l) The assembly is ready for tuning.

7.2.2.3 Antenna tuning

Final VSWR of the matched and balanced pair generally is less than 1.5. Depending on the time available, a set can be flown with a VSWR as high as 1.6 to 1.8, providing phase balance is satisfactory. No set should be flown with a VSWR greater than 1.9 to 2.0.

$$\text{VSWR} = \frac{\sqrt{\text{Forward Power}} + \sqrt{\text{Reflected Power}}}{\sqrt{\text{Forward Power}} - \sqrt{\text{Reflected Power}}}$$

The tuning procedure is as follows.

(a) Set up the tuning test equipment as illustrated in figure on this page and Photographs N and O.

(b) Position rocket motor so that the two antennas of 73 Mc frequency are parallel to the floor and approximately midway in tuning area or room.

(c) "Eyeball" accurately the positioning of the phase meter over the top 36 Mc antenna.

(d) Apply power to the dual test transmitter. Observe the operating procedure and precautions of both the transmitter and the power monitor. Check with the safety officer in the area before applying power.

(e) Tuning is done by adjusting four components (2 for each antenna). Tune for a reading between 0 and 1 ua on the phase meter, and a reading of less than 0.1 watt of reflected power. This is a rough tune. If the readings cannot be obtained, proceed to the next step.

(f) Turn off the rf power, remove phase meter to a safe location, and rotate the rocket motor so that the 36 Mc antennas are parallel to the floor.

(g) Reset the dual test transmitter and the power monitor for 36.8 Mc operation, replace the phase meter and perform steps (c) through (e) again.

(h) Continue fine turning until phase meter reads less than 0.5 ua, reflected power less than 0.05 watts, and the E-probe meter on each side of the rocket must be within 0.5 ua. This is a fine tune.

(i) Turn off the rf power and reset equipment for for 73.6 Mc tuning; this includes rotating the rocket motor, and repositioning the phase meter.

(j) Repeat step (h).

(k) Fill the variable capacitor cavity with silicon lubricant through the tuning hole. Repeat step (h).

(l) Insert both teflon plugs but do not trim. Recheck tuning and adjust if necessary.

(m) Turn off rf power and reset equipment for 36.8 Mc tuning.

(n) Repeat step (h).

(o) Insert both teflon plugs only; no silicon lubricant is used on 36 Mc antennas. Adjust tuning if necessary.

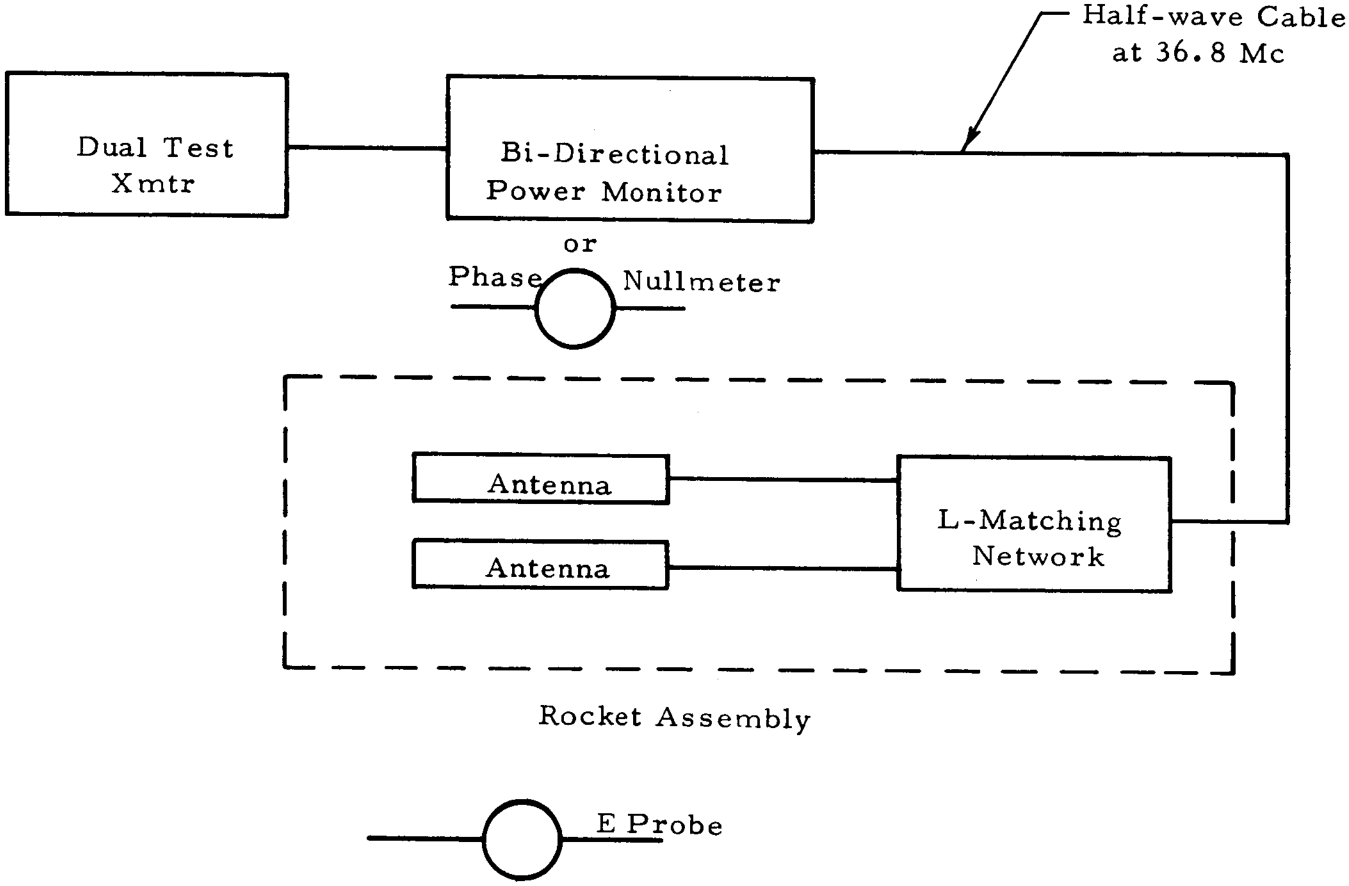
(p) Repeat step (h).

(q) Repeat step (i). Check and retune if necessary.

(r) Turn off the rf power .

(s) Position the teflon sleeving sizes 12 and 16 to allow soldering of the pin connections. (See Photograph M.) After soldering, relocate the sleeving so that there is teflon insulation between the center conductor and the outer conductor. Before proceeding to the next pin connection, fasten the top to the shockwave coupler. This avoids unnecessary strain on the pin connection by natural upward spring action of the copper coaxial. (See Photograph P.)

(t) Position another clamp just behind the headcap so that the buckle is rotationally opposite that buckle associated with shockwave couplers. Install coaxial cable holddown clips and tighten clamp. (See Photograph Q.)


Half-wave Cable
at 36.8 Mc
Dual Test
Xmtr
Bi-Directional
Power Monitor
or
Phase
Nullmeter
Antenna
Antenna
L-Matching
Network
Rocket Assembly
E Probe

(u) Repeat step (h) and record final readings.

(v) Reset all equipment for 36.8 Mc tuning.

(w) Repeat (h) and record final readings.

(x) Apply Loctite or Glyptol to the inductor tuning shafts and allow to harden. This prevents the shafts from moving. Cut the shafts flush with the antenna surface with diagonal pliers, being careful not to rotate the shaft.

(y) Remove the excess stainless steel strap material by bending repeatedly as close to the buckle as possible.

(z) Trim the excess teflon from the plugs until the plug is flush with the surface of the antenna. The tuned assembly with the sealed antennas is shown in Photograph R.

7.2.3 Pitot Static Payload

The method of instrumentation which should be followed is essentially the same as for the Grenade Payload, except for these items:

(a) The testing time is short enough so that one pack of batteries is adequate for testing and flight.

(b) The L-matching networks were originally clamped to the UDT-B can but are now bolted to plates which are attached to the four upright posts of the payload structure.

(c) The antenna cable bending jigs are different.

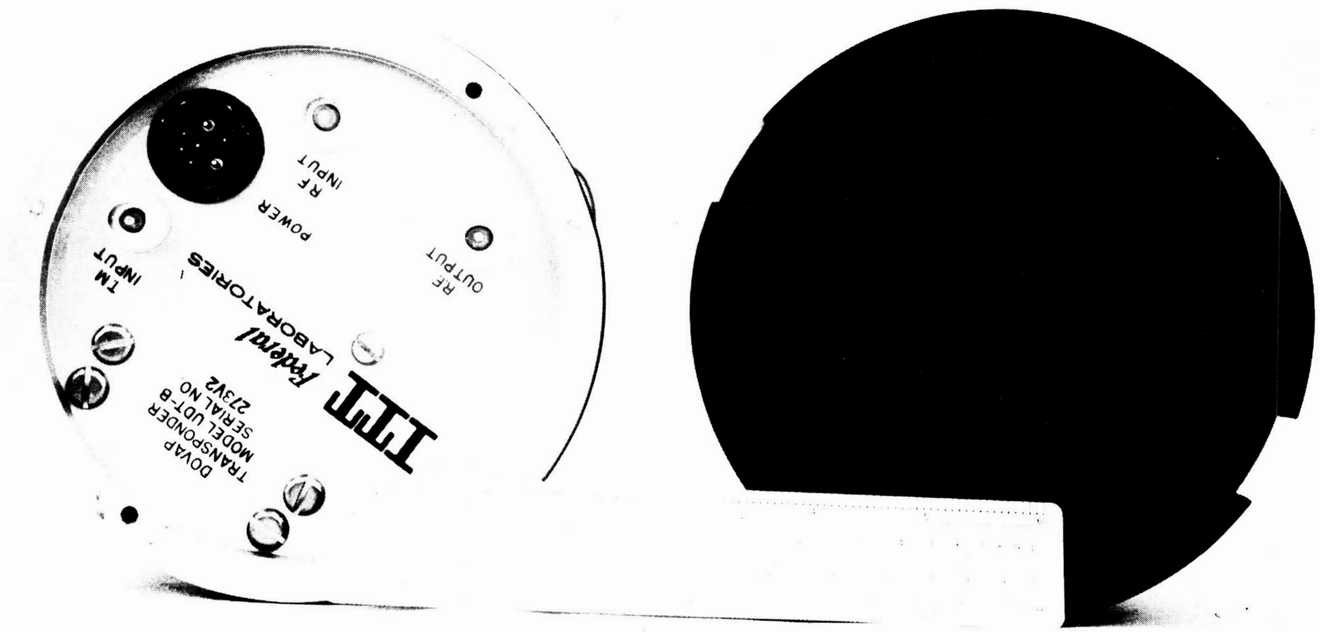
(d) Rotational position of the antennas is determined by the matching network location, but otherwise is the same as for the Grenade.

(e) Data to the TM input is commutated so that multiple data can be telemetered over the single TM channel.

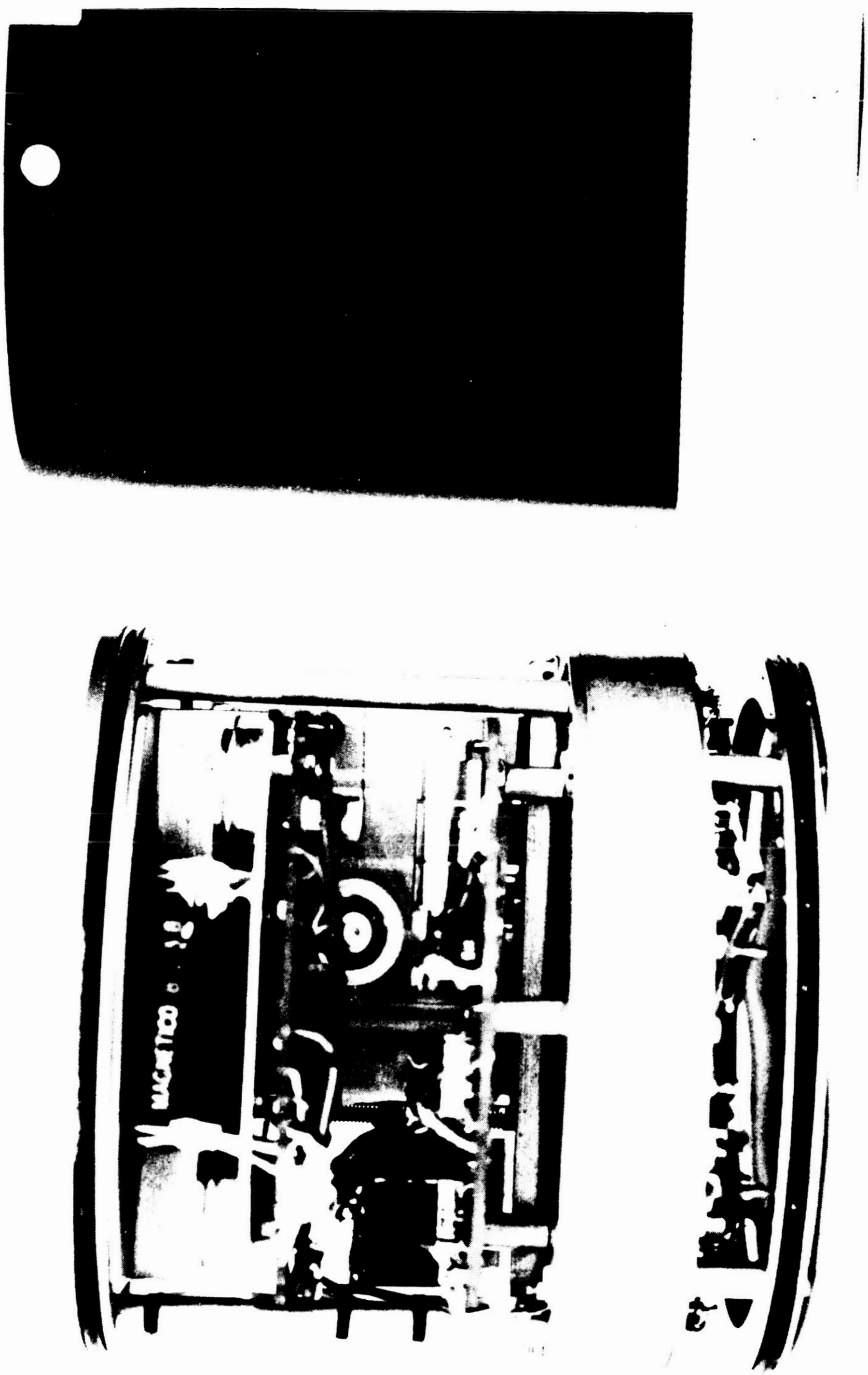
Photographs S and T illustrate the types of bends for the copper coaxial cable (before mounting the L-matching networks on their support plates), but not necessarily the positioning and location.

Photograph U shows the transponder location. (Note that the L-matching networks are no longer attached to the UDT-B can.)

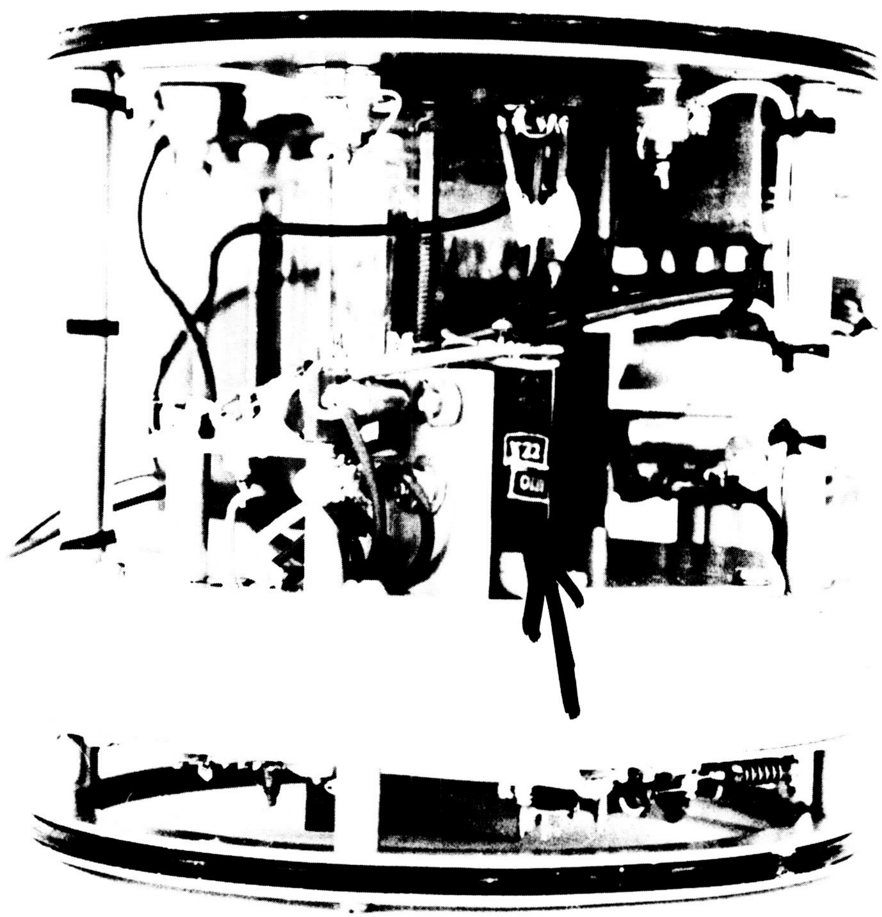
Photograph V illustrates the arrangement of the flexible rf cables with respect to the UDT-B transponder.



PHOTOGRAPH A

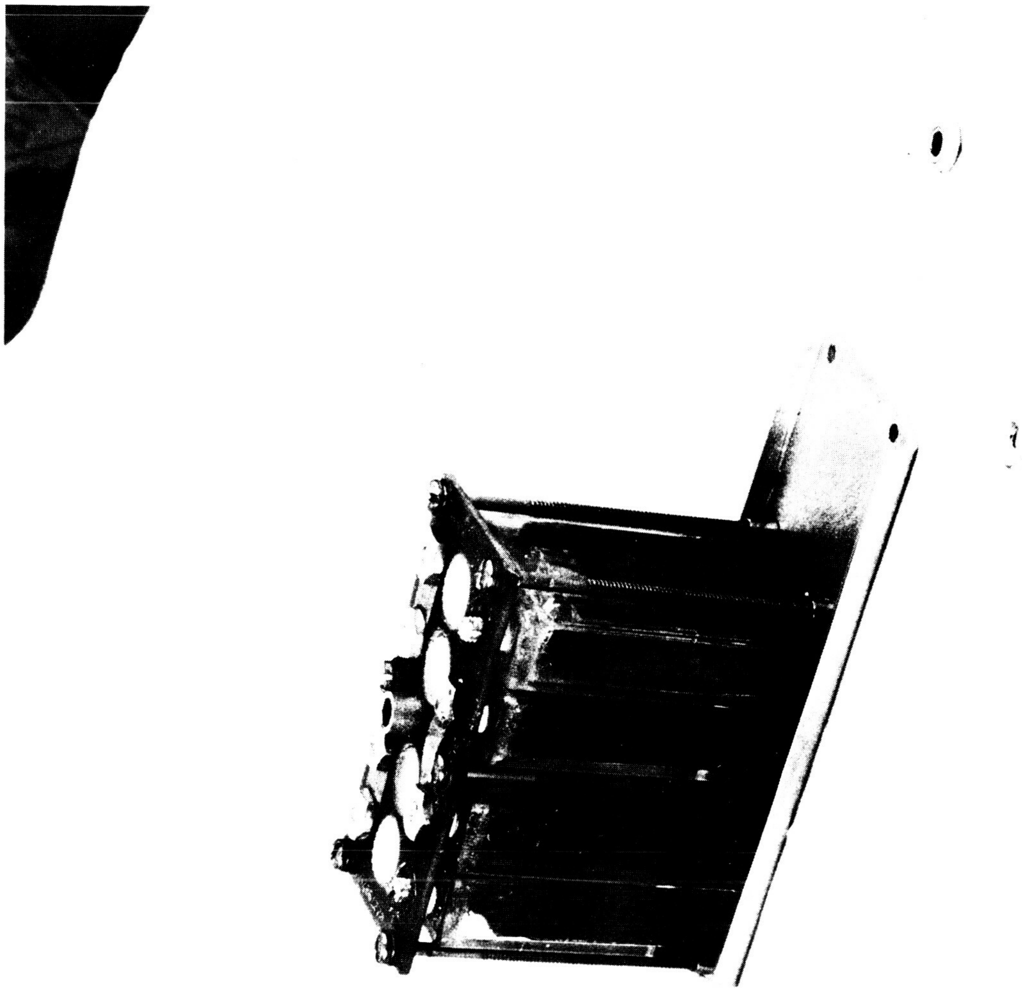


PHOTOGRAPH B

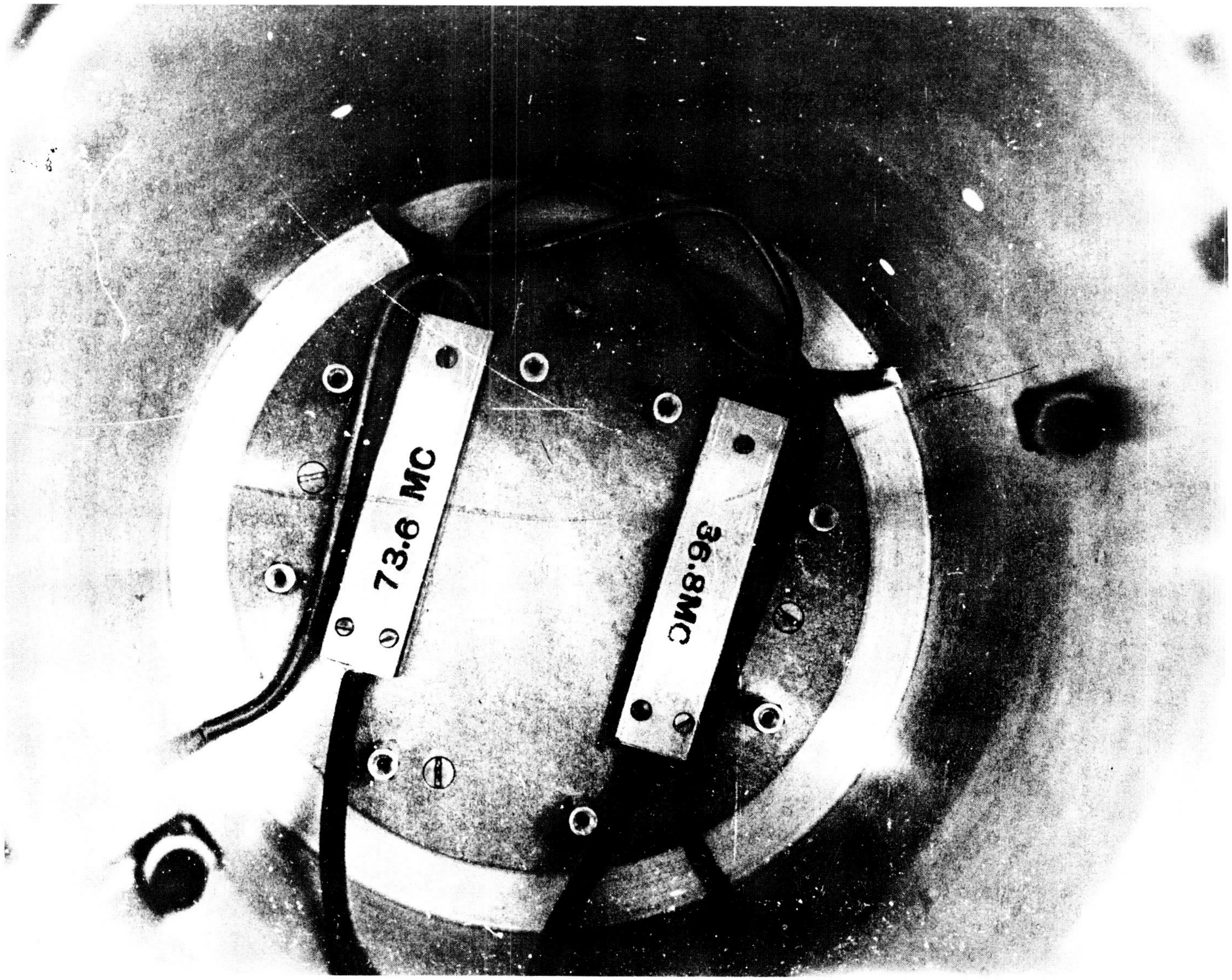


PHOTOGRAPH C

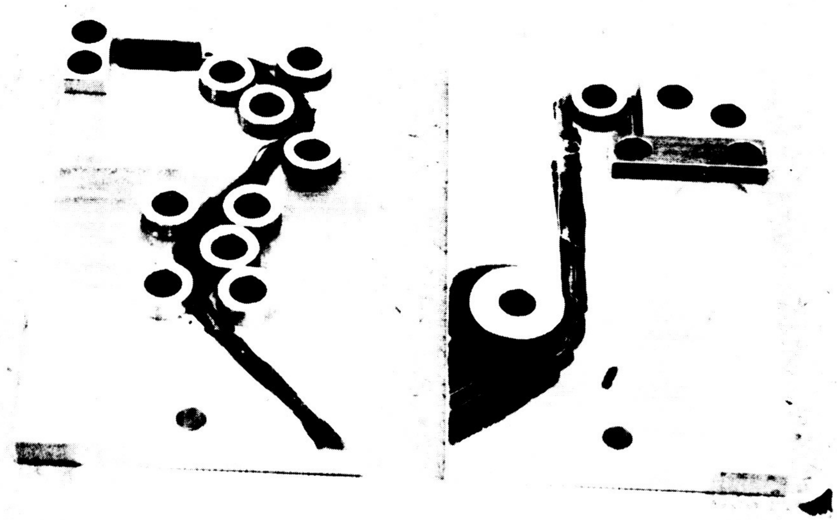
PHOTOGRAPH D



PHOTOGRAPH E

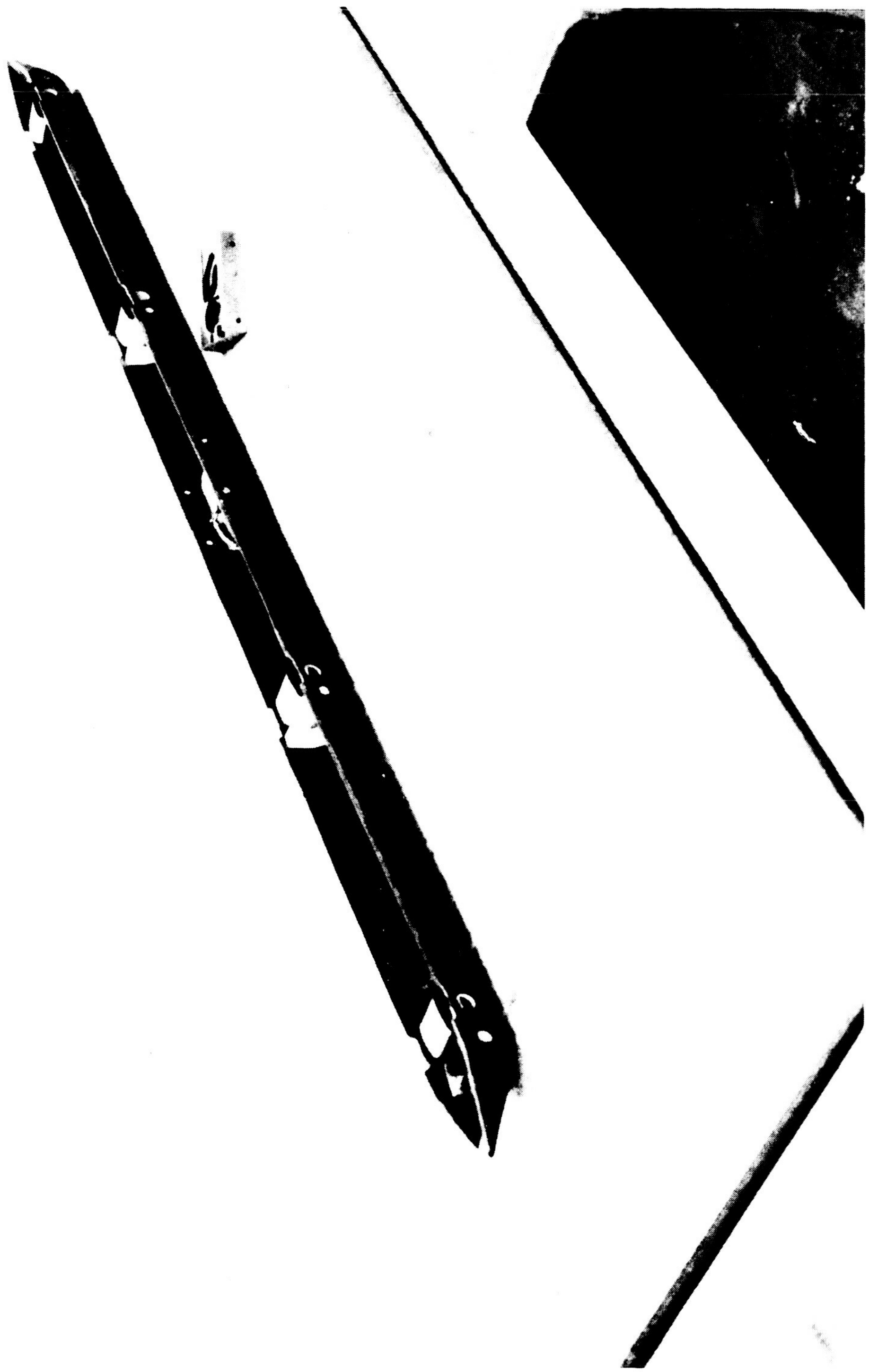


PHOTOGRAPH F



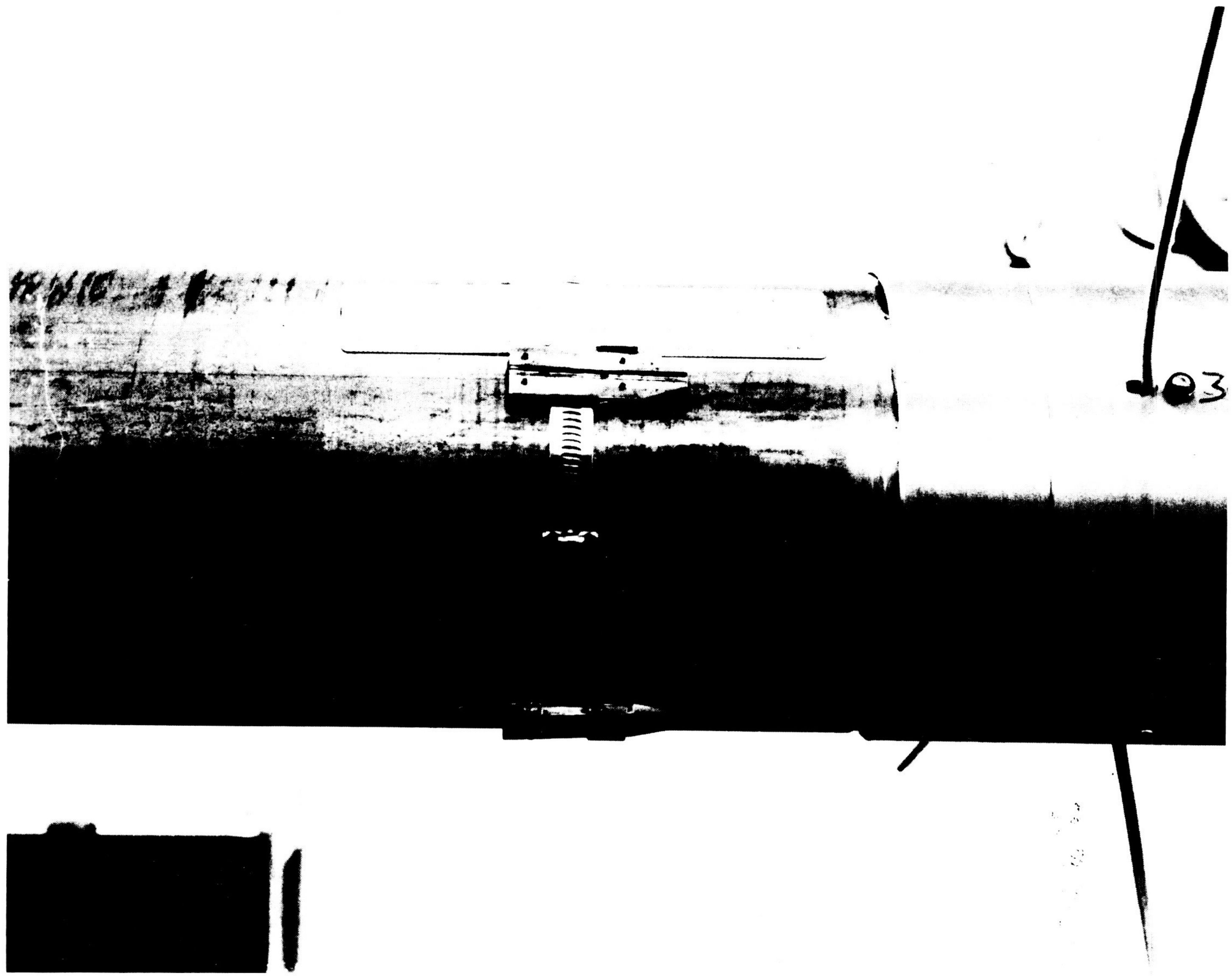
PHOTOGRAPH G

PHOTOGRAPH H

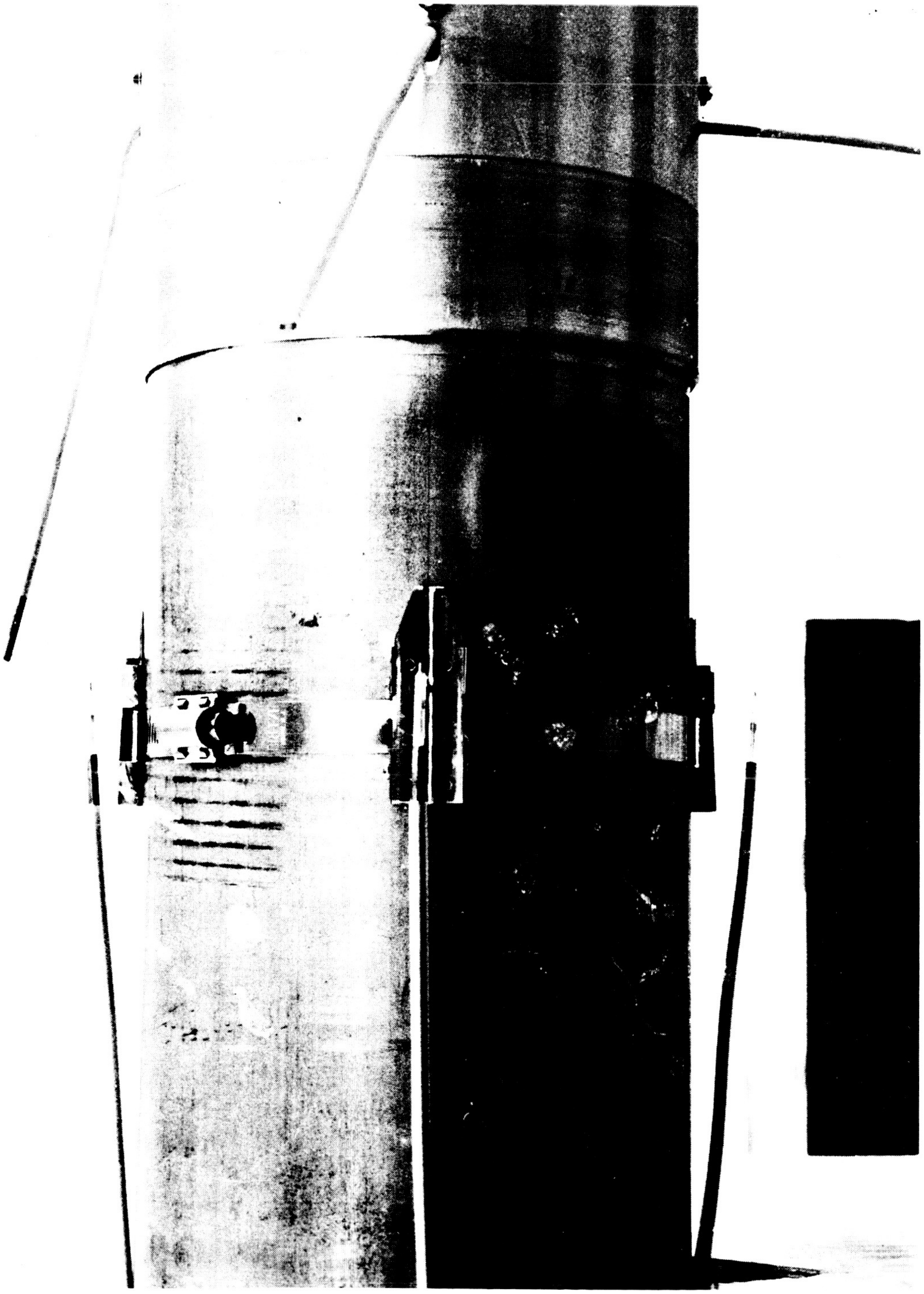


PHOTOGRAPH I

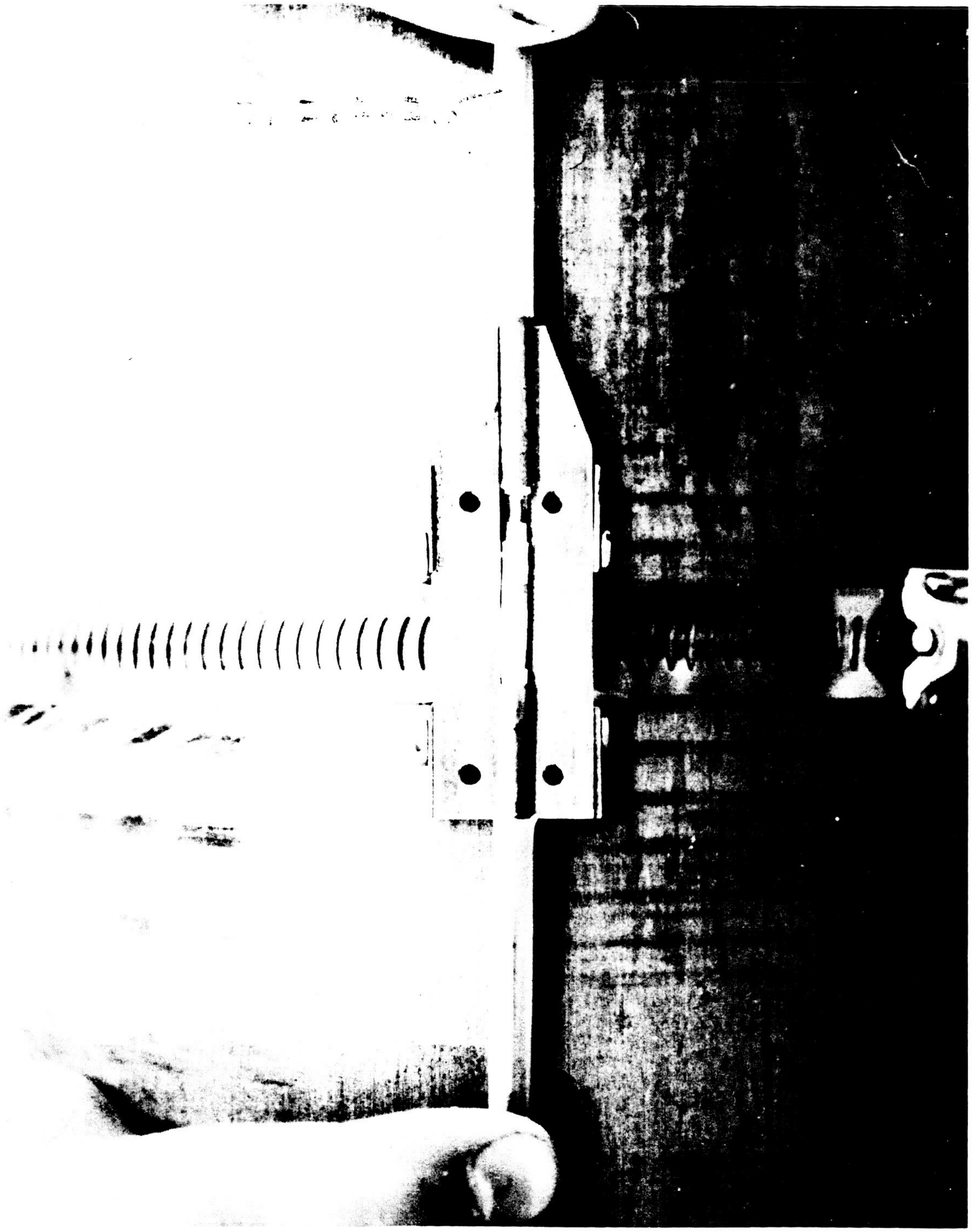
PHOTOGRAPH J



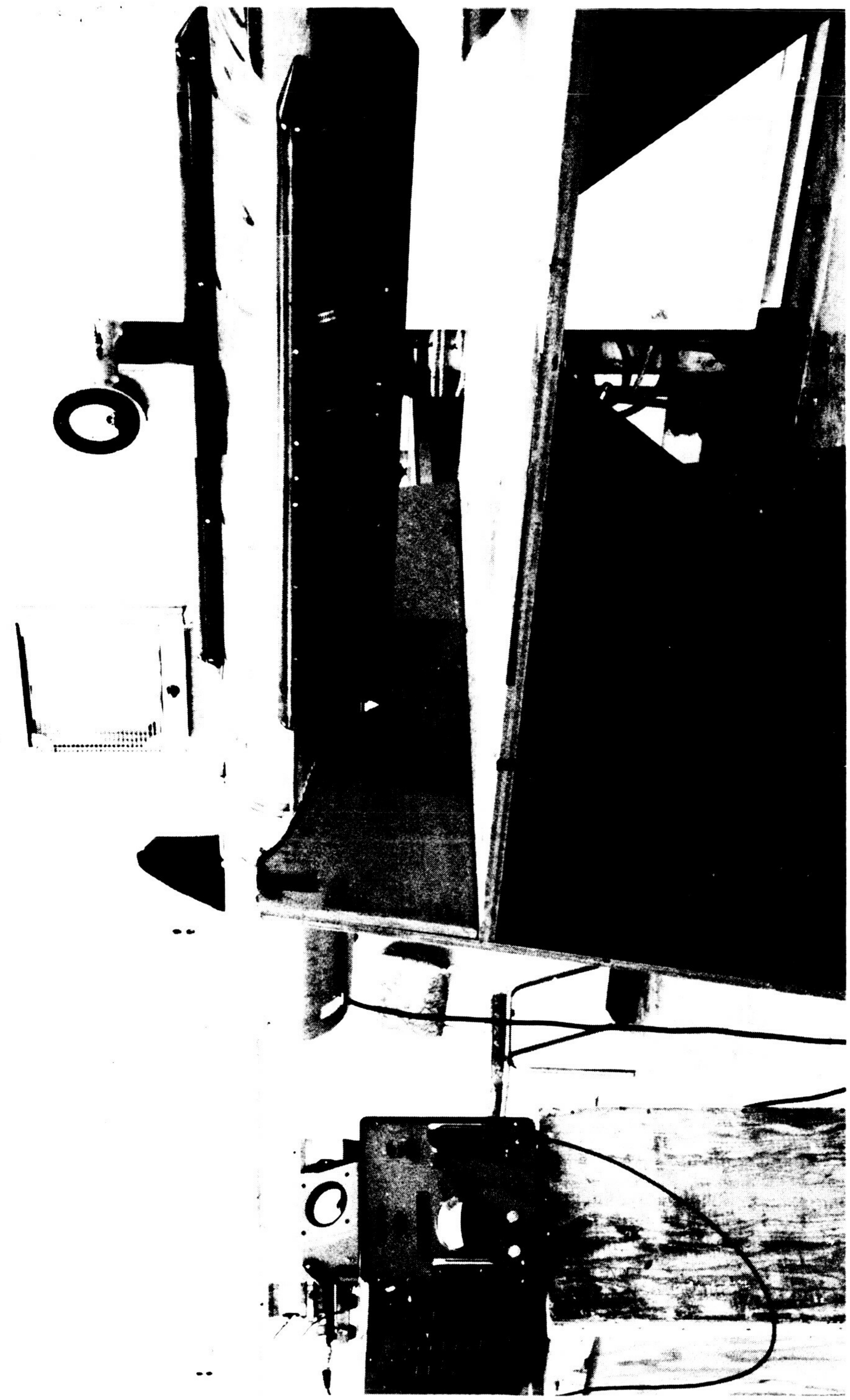
PHOTOGRAPH K



PHOTOGRAPH L

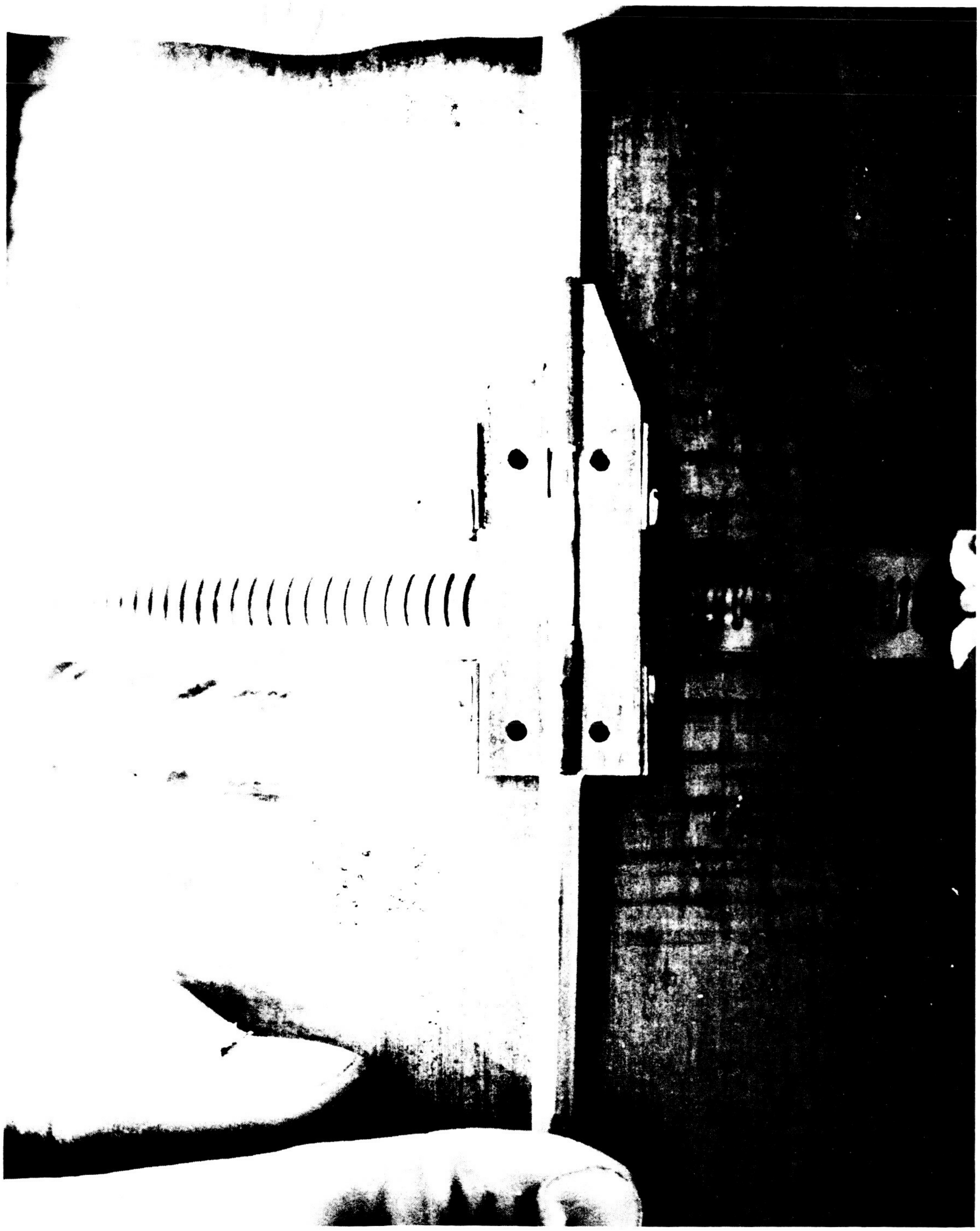


PHOTOGRAPH M

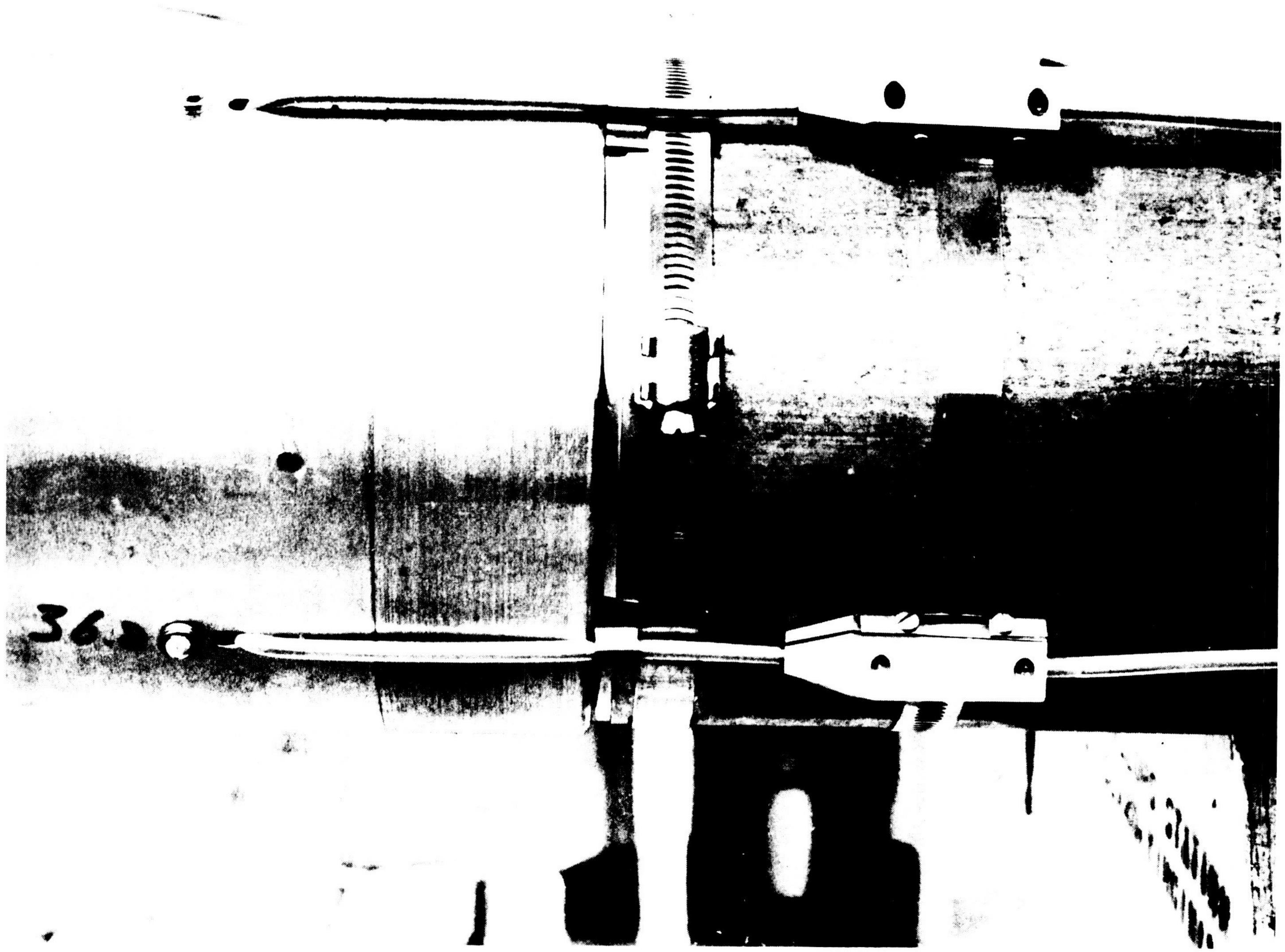


PHOTOGRAPH N

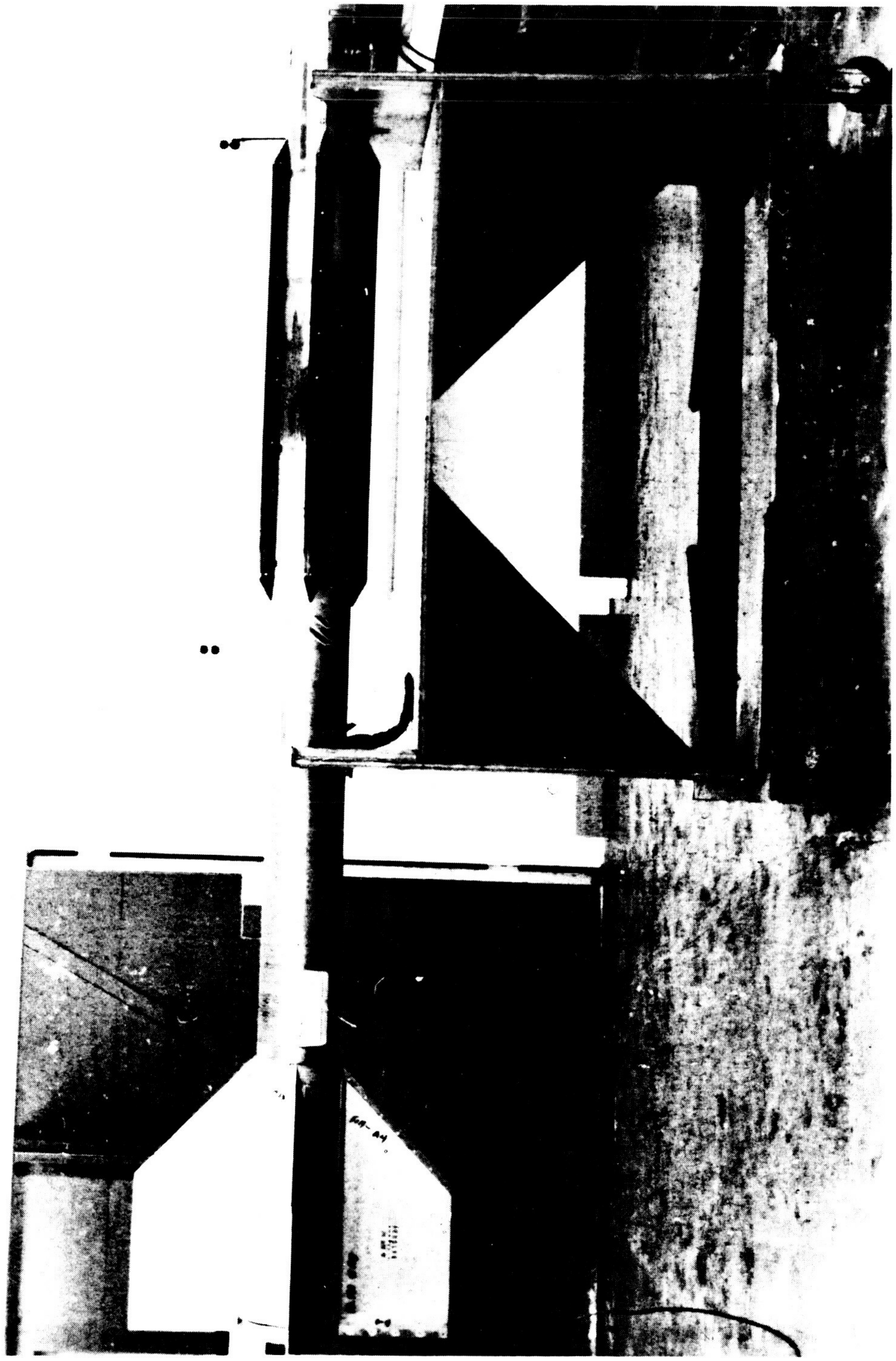
PHOTOGRAPH O



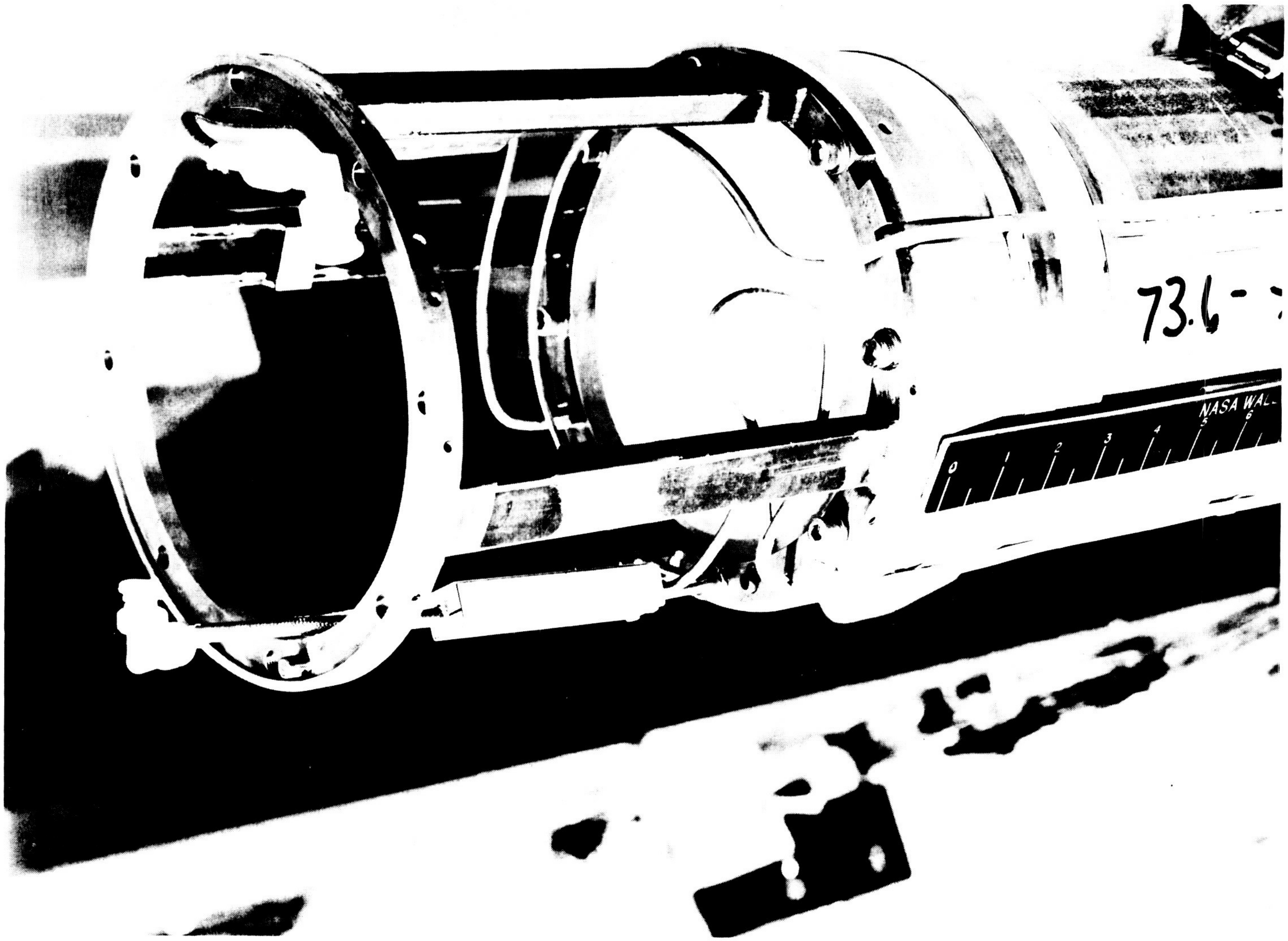
PHOTOGRAPH P



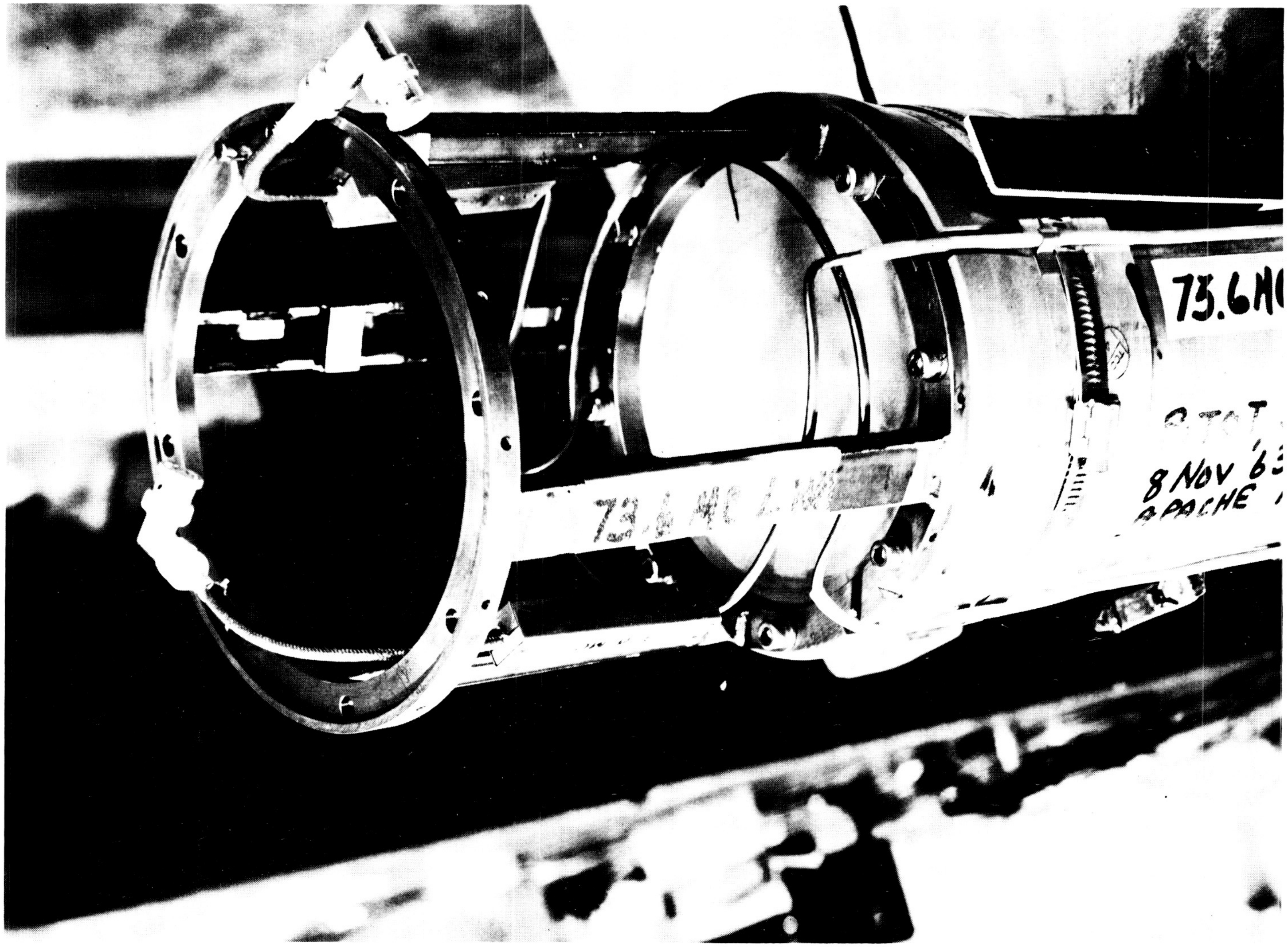
PHOTOGRAPH Q



PHOTOGRAPH R

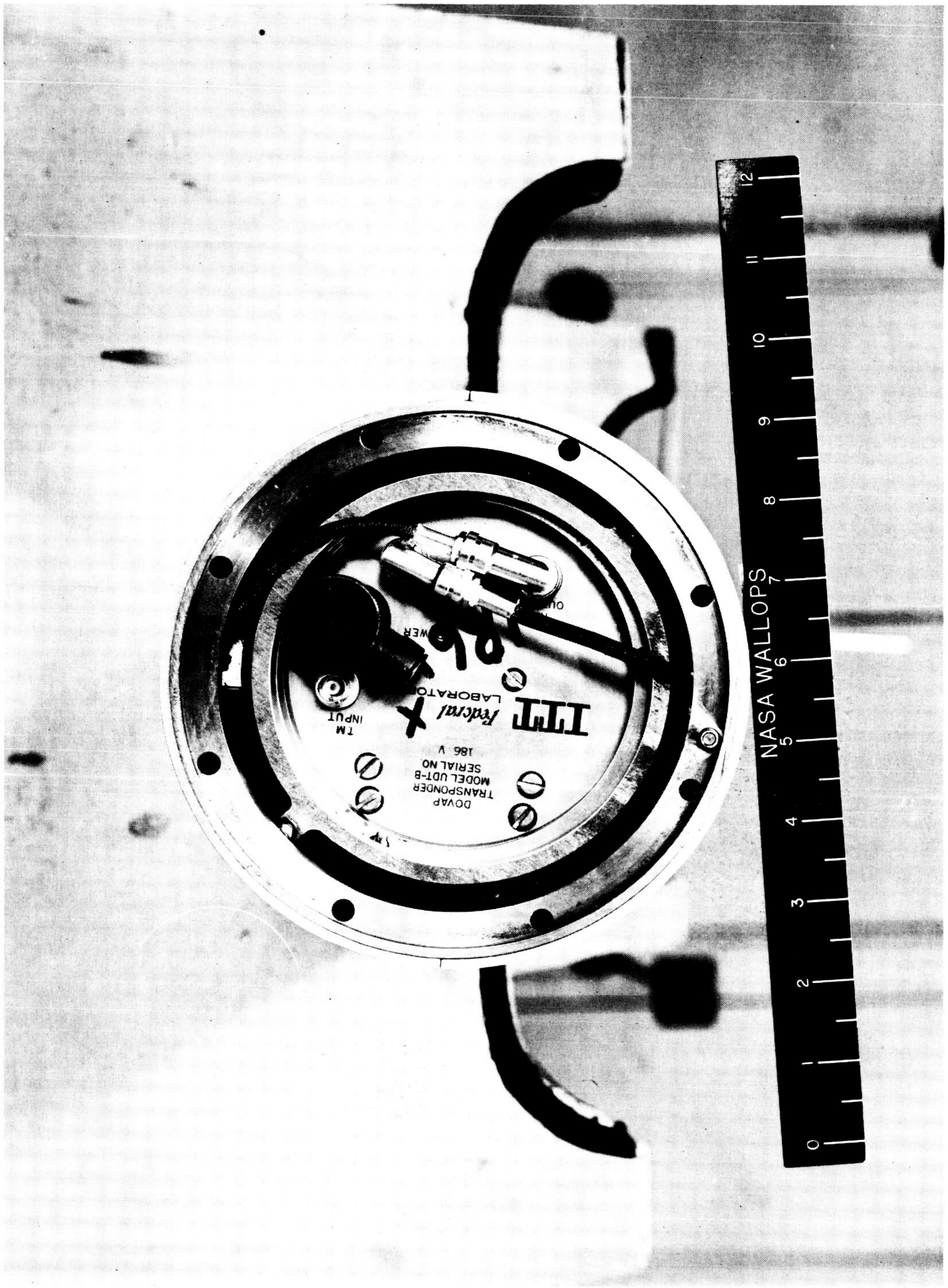


PHOTOGRAPH S



PHOTOGRAPH T

PHOTOGRAPH U



PHOTOGRAPH V

BIBLIOGRAPHY

1. Hines, Phebe, DOVAP Systems and Data Reduction Methods, Physical Science Laboratory, New Mexico State University, January 1962, p. 44.

2. Handbook of Chemistry and Physics, 38th Edition, p. 2144.

3. Some Aids for Estimating Atmospheric Refractive Conditions, Interim Research Report, Task 31, Meteorological Aspects of Refraction and Propagation of Radar Waves, USN Weather Research Facility, Bldg. R-48, USN Air Station, Norfolk 11, Virginia.

4. Joosten, W. L., R. J. Sabin, E. D. Lee, W. G. Gammill and W. F. Montz, Manual for the NASA/SSD System, Physical Science Laboratory, New Mexico State University, February 1963.

5. Joosten, W. L., The Theory of a Radio Frequency Interferometer Internal-External Junction, Physical Science Laboratory, New Mexico State University, September 1965.

6. Joosten, W. L. and E. D. Lee, Analysis of a Circularly Polarized Turnstile Antenna, Physical Science Laboratory, New Mexico State University, January 1958.

7. Henry, D. G., 36.8 Mc Helix for DOVAP Application, Physical Science Laboratory, New Mexico State University, January 1965.

8. Joosten, W. L., Working Drawings for 36.8 Mc Turnstile Antenna, Physical Science Laboratory, New Mexico State University, August 1960.

9. Joosten, W. L., Working Drawings for 73.6 Mc and 36.8 Mc Helix Antennas, Physical Science Laboratory, New Mexico State University, February 1963.

10. Taber, John E., "Theory and Application of Phase Lock Loop Discriminator," An STL Interoffice Correspondence, 21 July 1959.

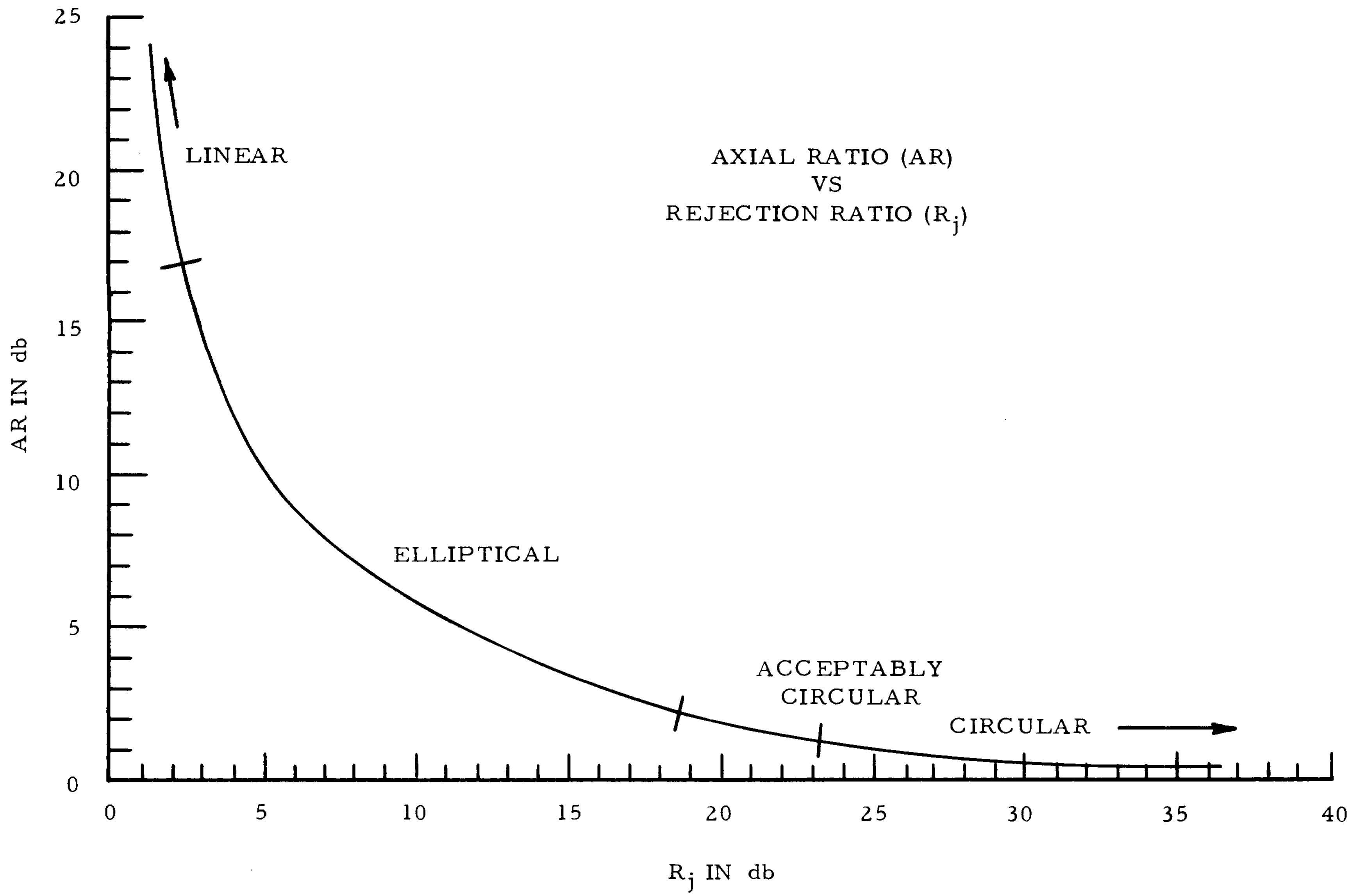
11. Specifications for the Mod. 220 Phase Lock Tracking Filters, Electrac, Inc., Anaheim, California.

12. Mitra, S. K., The Upper Atmosphere, Second Edition, 1952, The Asiatic Society, Calcutta, India.

13. Seddon, J. C., Rocket Investigations of the Ionosphere by a Radio Propagation Method, 1954, Naval Research Laboratory, Report 4304.

APPENDIX A

POLARIZATION (AXIAL RATIO) AND REJECTION


AXIAL RATIO (AR)
VS
REJECTION RATIO (R_j)
LINEAR
ELLIPTICAL
ACCEPTABLY
CIRCULAR
CIRCULAR
AR IN db
R_j IN db
0
5
10
15
20
25
30
35
40

APPENDIX B

SSD SINGLE PATH OPERATION WITH ELLIPTICALLY POLARIZED MISSILE TRANSMITTED SIGNALS

When the signal transmitted from a missile departs from linear polarization, the roll correction system of SSD is subjected to operation with unequal RH and LH signals.

From Appendix A, it is seen that a RH polarized wave with an AR (axial ratio) of 3 db contains also a LH component which is down by -16 db compared to the major RH component. It will also be noted that a RH truly circular wave of 0 db AR has no LH component. Likewise, a linear signal contains equal RH and LH components.

The SSD roll correction system utilizes the RH and LH components of the linearly polarized wave being transmitted from the missile to determine the missile roll. (See ref. 4, p 66.)

The RADINT ground antenna system is designed to separate the linear signal into its equal RH and LH components. Ideally, the separation by the antenna is perfect. Actually, some residual RH component exists in the LH channel and some residual LH exists in the RH channel. The ratio of the desired signal to the undesired signal is termed the rejection ratio, or Rj. The rejection ratio obtained by the RADINT antenna system is typically 25 db, (AR of 1.0 db).

When unequal components are transmitted from the missile, the overall "system" rejection ratios (RH and LH) will be affected by the AR of the missile signal.

Table B1 shows the signals presented to the RH and LH RADINT receivers for a RH elliptical wave with various AR, assuming an Rj of 25 db for the ground antenna.

TABLE B-1

RH Polarization AR db	LH Rcvr. LH to RH Ratio db	RH Rcvr. RH to LH Ratio db
2	5	45
3	9	41
4	11.5	38.5
6	15.5	34.5
8	18	32

It can be seen that as the RH wave becomes more circular, AR of 0 db, the RH receiver signal becomes more pure, while the LH signal becomes more diluted with the RH signal.

The signal presented to the Doppler receiver is limited by the receiver. When two signals are mixed in a receiver, the resultant is a beat note between the two. When a limiter removes the amplitude variation, the resultant is a phase modulated signal, the phase modulation being of the form

$$\phi a + (\phi \max \text{Sin } \Delta \ Wt),$$

where ϕa is an arbitrary constant phase, ΔW is the difference frequency between the two signals: $W_{LH} - W_{RH} = 2\ Wr$ (roll), and

$$\phi_{max} = \text{arc Sin } \frac{\text{RH amplitude}}{\text{LH amplitude}} ,$$

where it is assumed that the RH/LH is less than unity.

As RH/LH approaches unity, the phase modulation departs from the simple sinusoidal relation to ΔW, and takes on higher order harmonic terms in ΔW.

The maximum phase acceleration caused by this phase modulation is the derivative of the phase modulation. In Table B-2, the maximum phase and phase acceleration is shown. The missile spin frequency is fr.

TABLE B-2

AR db	LH ϕ max Rad	$\frac{d}{dt}\phi_{max}$ Rad/sec.
2	0.6	7.5 fr
3	0.37	4.6 fr
4	0.27	3.4 fr
6	0.17	2.1 fr
8	0.13	1.6 fr

If the two Doppler receiver signals derived from a RH polarized transmitted signal are combined to produce a Doppler signal, the phase modulation term carried by the LH receiver signal will be transferred to the Doppler,

$$D = 2fo \frac{v}{c} + \phi_M \operatorname{Sin} 2W_r t,$$

where fo is the missile transmitted frequency. Thus the instantaneous Doppler frequency (which includes the phase modulation term) is different by some f from the true Doppler frequency. However, the Doppler frequency as averaged over a half missile roll cycle does not differ from the true Doppler. The phase term caused by the LH residual in the RH signal has been neglected.

The Doppler receiver output signal consists of Doppler on a bias frequency, which is fed to a phase lock tracking filter.

This type tracking filter (TF) can track a signal which has an acceleration of

$$\dot{\phi} = K B^2$$

where K is 0.167 (10) or 0.15 (11). Table B-3 shows the smallest BW setting at which the tracking filter can be set (B).

TABLE B-3

AR db	fr = 10 cps	fr = 5 cps
2	8.7	6.1
3	6.9	4.8
4	5.8	4.1
6	4.6	3.2
8	4.0	2.8

This minimum TF BW setting is calculated on the basis of 1/3 radian loop error, where the operation is becoming marginal.

Should the TF operation become too marginal, the Doppler data can be recovered by hand counting. Should antenna aspect cause the LH signal to become unusable at times, the Doppler data can be averaged through these areas with no loss in accuracy.

APPENDIX C

THE SENSE OF CIRCULARLY POLARIZED ANTENNAS

(See ref. 4, pp 145 and 150.)

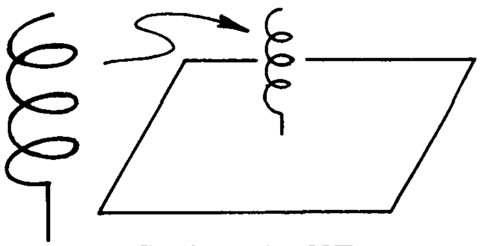
The Sense of Circularly Polarized Antennas

In most systems involving trajectory measurement, the polarization sense of the circularly polarized antennas is quite important. The sense of a circularly polarized antenna is generally stated as either right hand (CW), or left hand (CCW) and this sense must be correlated with the antenna operating mode of reception or transmission.

Other terminology is used in connection with ionospheric work. North of the magnetic equator, an ordinary signal is polarized LH down-coming and RH up-going. The extraordinary signal is polarized RH down-coming and LH up-going. Polarities are reversed south of the magnetic equator.

The following diagrams illustrate the polarization senses of various antenna configurations.

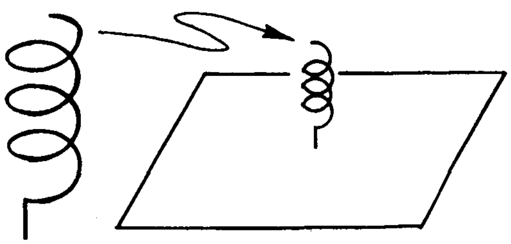
Helical Antennas



GND. PLANE

LH Receiving

LH Transmitting

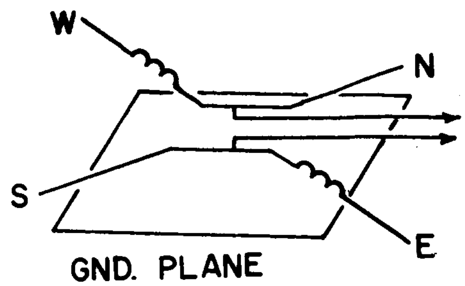


GND. PLANE

RH Receiving

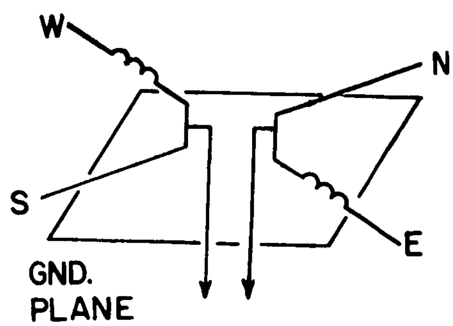
RH Transmitting

Inductive Stub Phasing (Unphased elements cut capacitive)



RH Receiving

LH Transmitting



LH Receiving

RH Transmitting

DISTRIBUTION LIST

Copy No.	
1	Karl Medrow, Head Sounding Rocket Branch, Code 721 Goddard Space Flight Center Greenbelt, Maryland 20771
2 - 4	National Aeronautics and Space Administration Goddard Space Flight Center Greenbelt, Maryland Attention: John I. Hudgins, Jr. Code 671.3
5	National Aeronautics and Space Administration Goddard Space Flight Center Greenbelt, Maryland Attention: Wendell S. Smith, Code 651
6	National Aeronautics and Space Administration Western Operations Office 150 Pico Blvd. Santa Monica, California Attention: Don Keaveny
7	PSL/Missile Position Instrumentation
8 - 33	PSL/Technical Library